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Seismo at School

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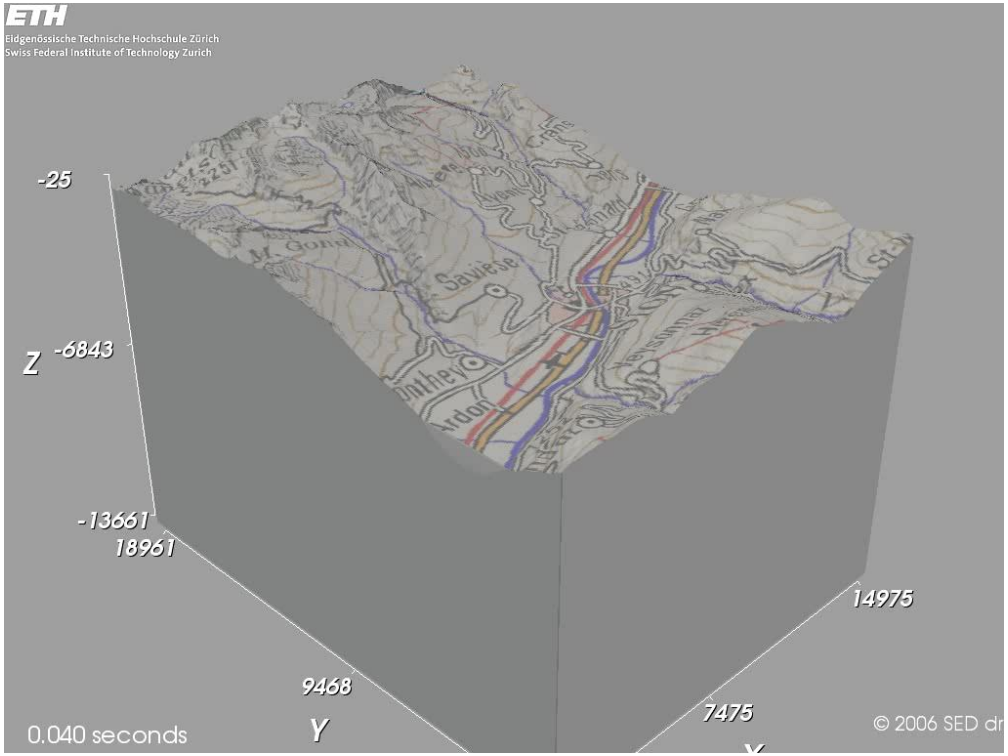
Local Seismic Hazard in Alpine Environment
From Site Effects to Induced Phenomena

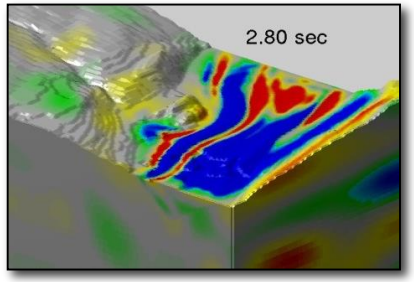
Donat Fäh
Swiss Seismological Service, ETH Zürich



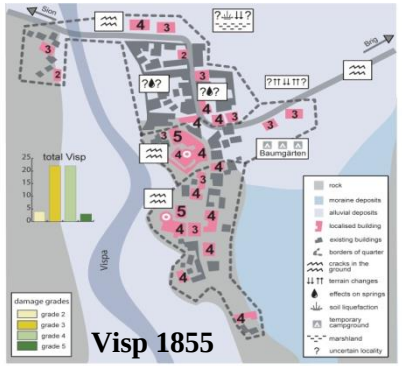
Numerical simulation
Earthquake at Sion/Sierre
January 25, 1946

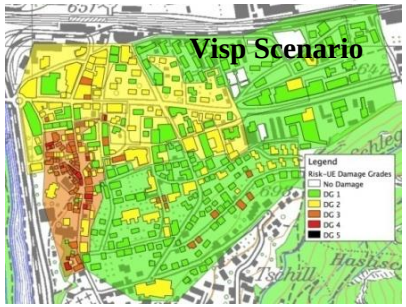
Scientific motivations

Understand the full hazard chain induced by earthquakes. Particular focus is on the development of methods suitable for the regions of moderate seismicity (e.g. Valais, Switzerland).



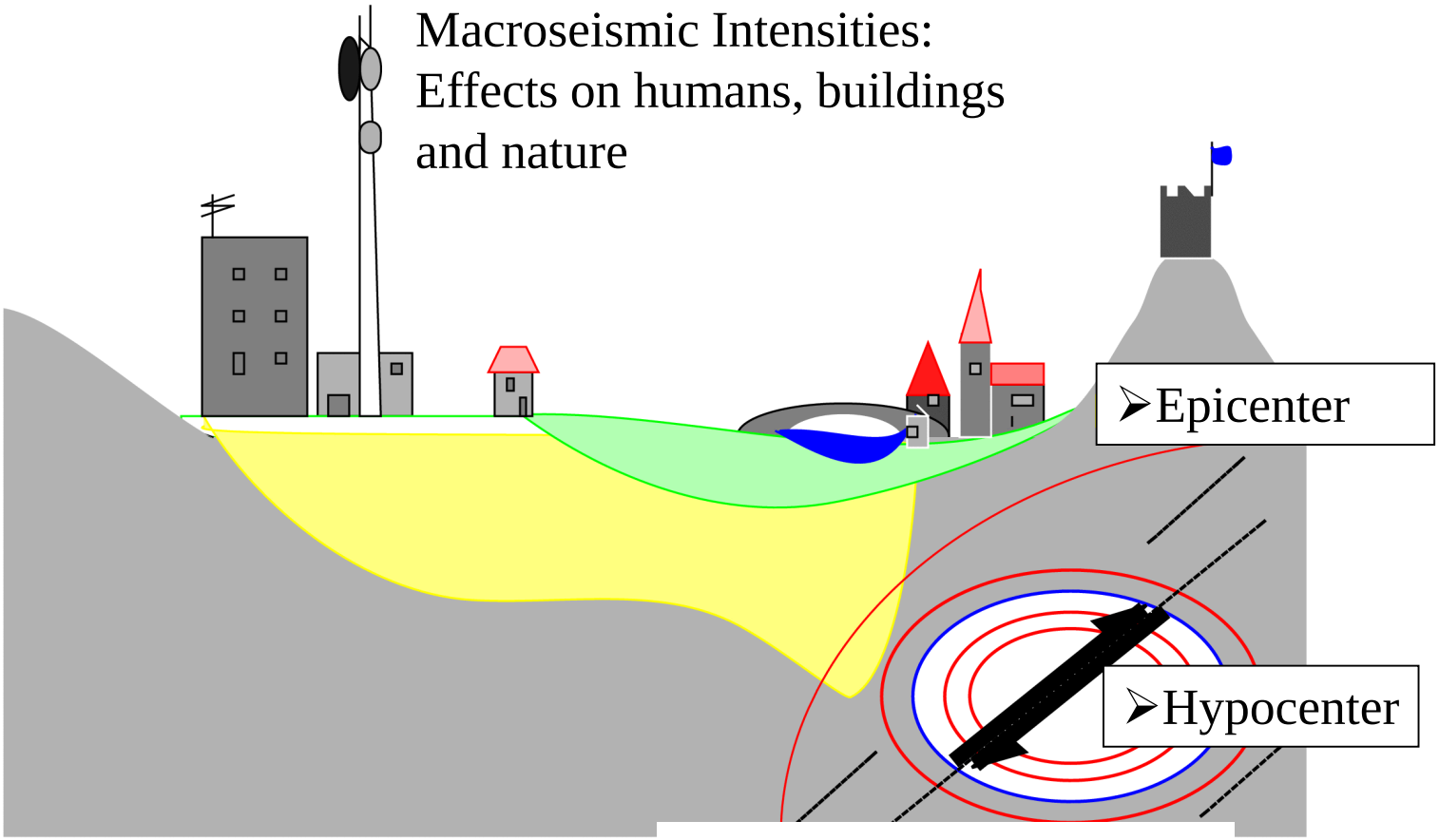
- **Understanding of observed ground motions: Source – Path - Site.**
- Identification of active faults.
- Seismicity pattern.
- Precursory phenomena (“Exotic sensors”).
- **Earthquake-induced phenomena: Landslides, liquefaction.**
- **Linking historical and recent observations.**
- Seismic hazard and risk scenarios.





Site Effect Evaluation- Microzonation

Macroseismic Intensities:
Effects on humans, buildings and nature



Magnitude is related to the energy release

Macroseismic Scale

European Macroseismic Scale (EMS) 1998

Intensity	Definition (short form)
I	Not felt
II	Scarcely felt
III	Weak
IV	Largely observed
V	Strong
VI	Slightly damaging
VII	Damaging
VIII	Heavily damaging
IX	Destructive
X	Very destructive
XI	Devasting
XII	Completely devasting

Macroseismic Intensity describes the effects of an earthquake in particular areas (e.g. village, quarter of city,..)

In the detailed scale,
we distinguish for buildings :

a) **Vulnerability classes (A-F)**

b) **Damage grades (1-5)**

EMS (1998): European Macroseismic Scale 1998. Grünthal, G. et al. (eds.)

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Historical Earthquakes

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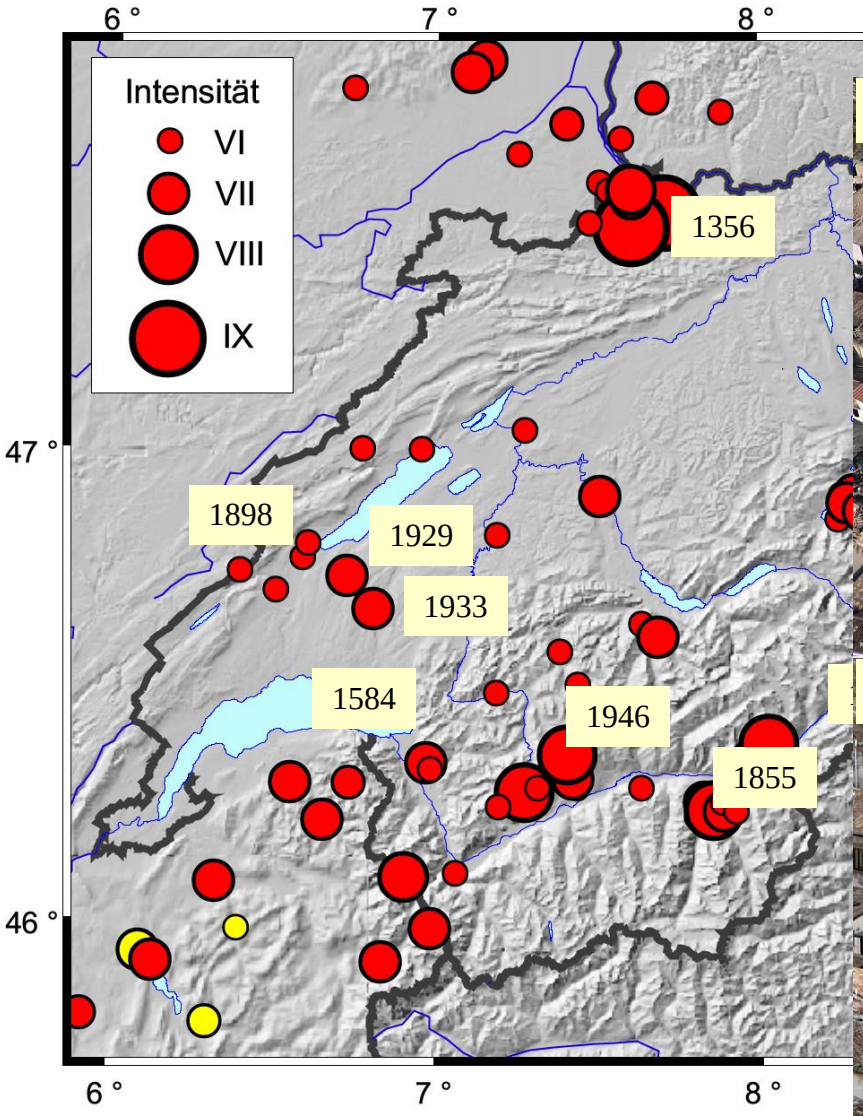
Damaging events determine the seismic hazard



L‘Aquila 2009 (AP Photo/Guardia Forestale)

L'Aquila 2009 (AP Photo/Alessandra Tarantino)

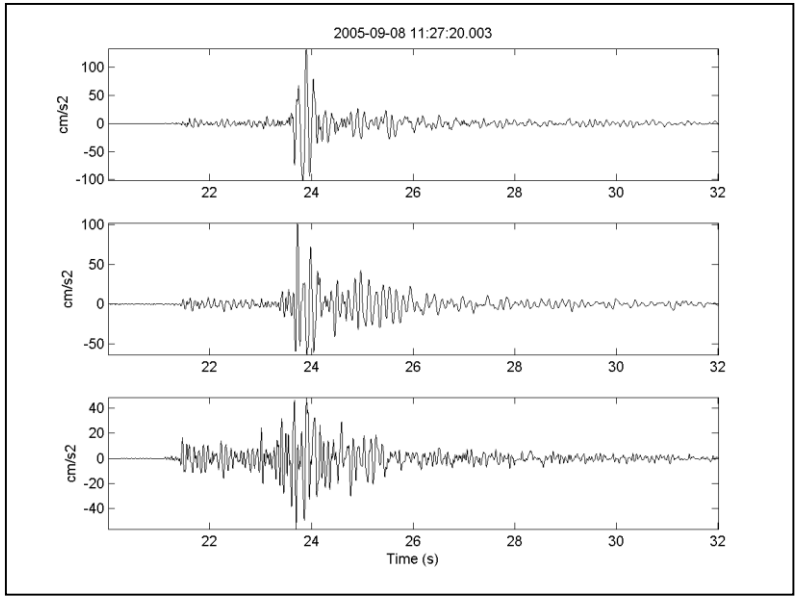
Ground motion and related damage

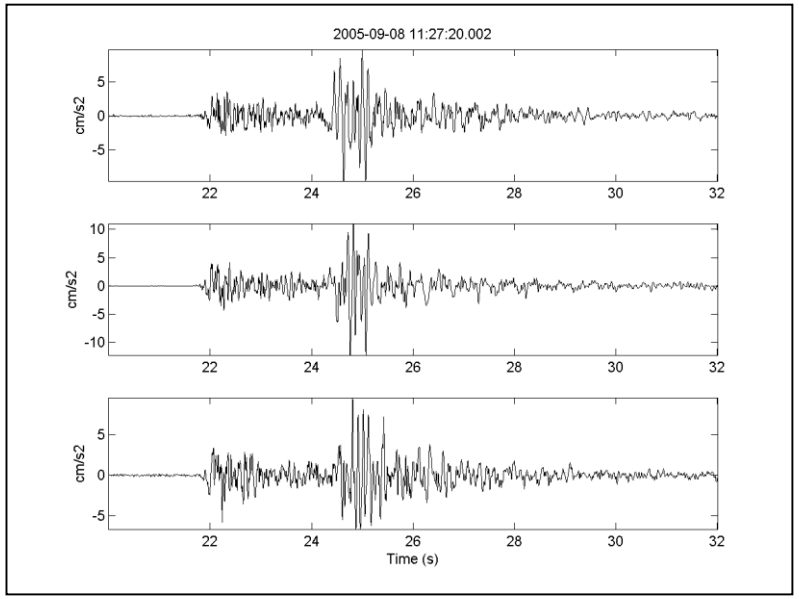
Factors that influence the characteristics of the ground motion:

1) Magnitude of the event (+ frequency content of radiated waves);
2) Epicentral distance (ground motion attenuation);
3) Local ground conditions:

Unconsolidated sediments when compared to bedrock have the following effects:

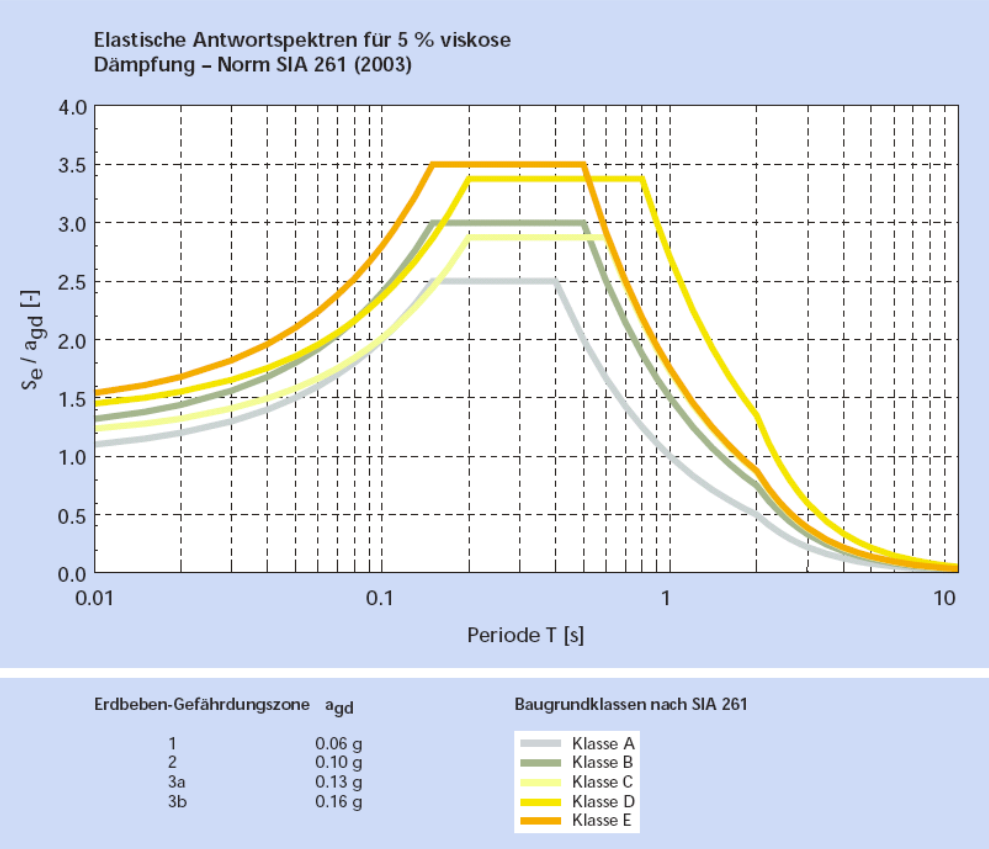
a) Horizontal ground motion is generally much larger than the vertical;
b) High-frequency waves are damped;
c) Low-frequency waves are amplified (e.g. resonances);
d) Duration of ground motion is generally increased (e.g. local surface waves)





Site-effects in building codes (EC8)

Different elastic design spectrum for different soil classes

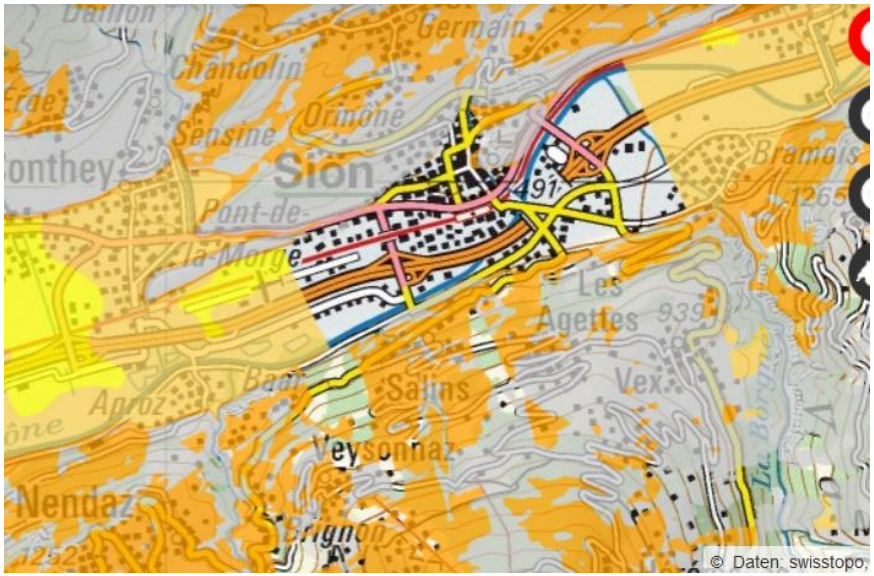


Swiss Building Code SIA261

Soil class covers a large variety of conditions

Are conservative at long periods

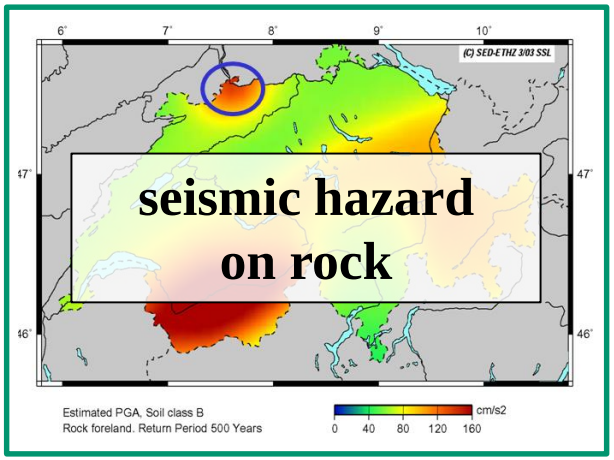
Soil class maps to support the application of the code (http://erdbeben.admin.ch)

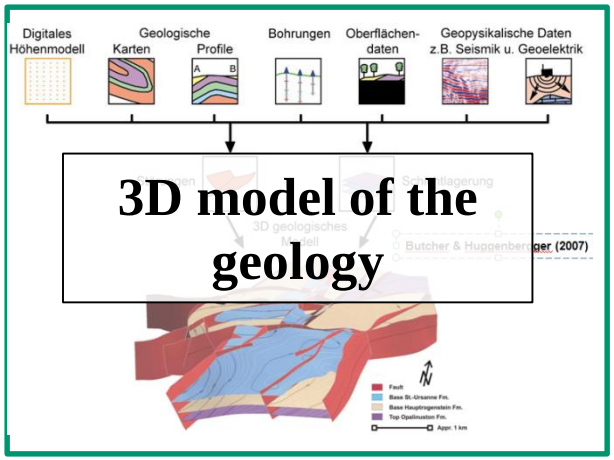


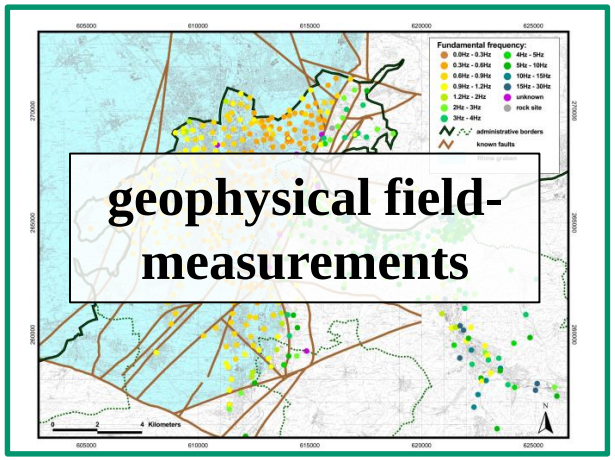
How to make the assessment more site-specific?

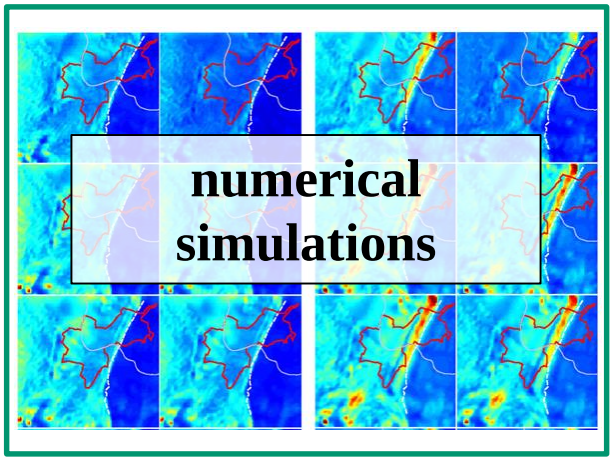
Example: microzonation for wider Basel region (2003-2009):

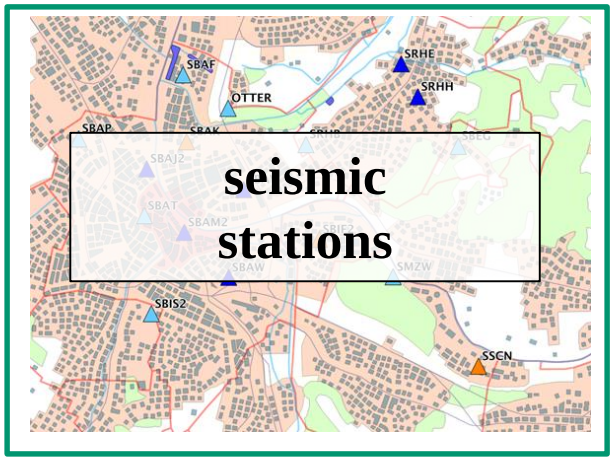
- Design spectra based on ….

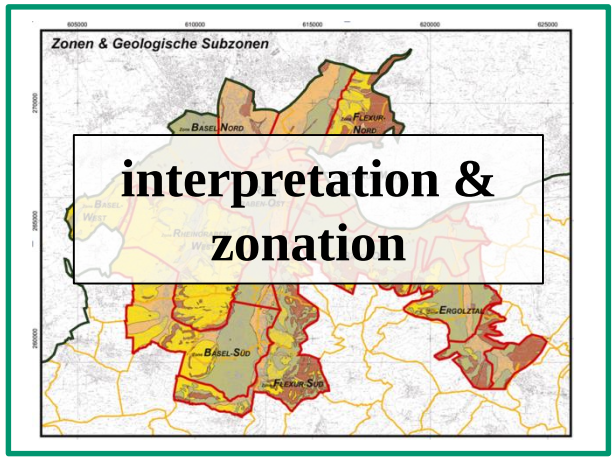








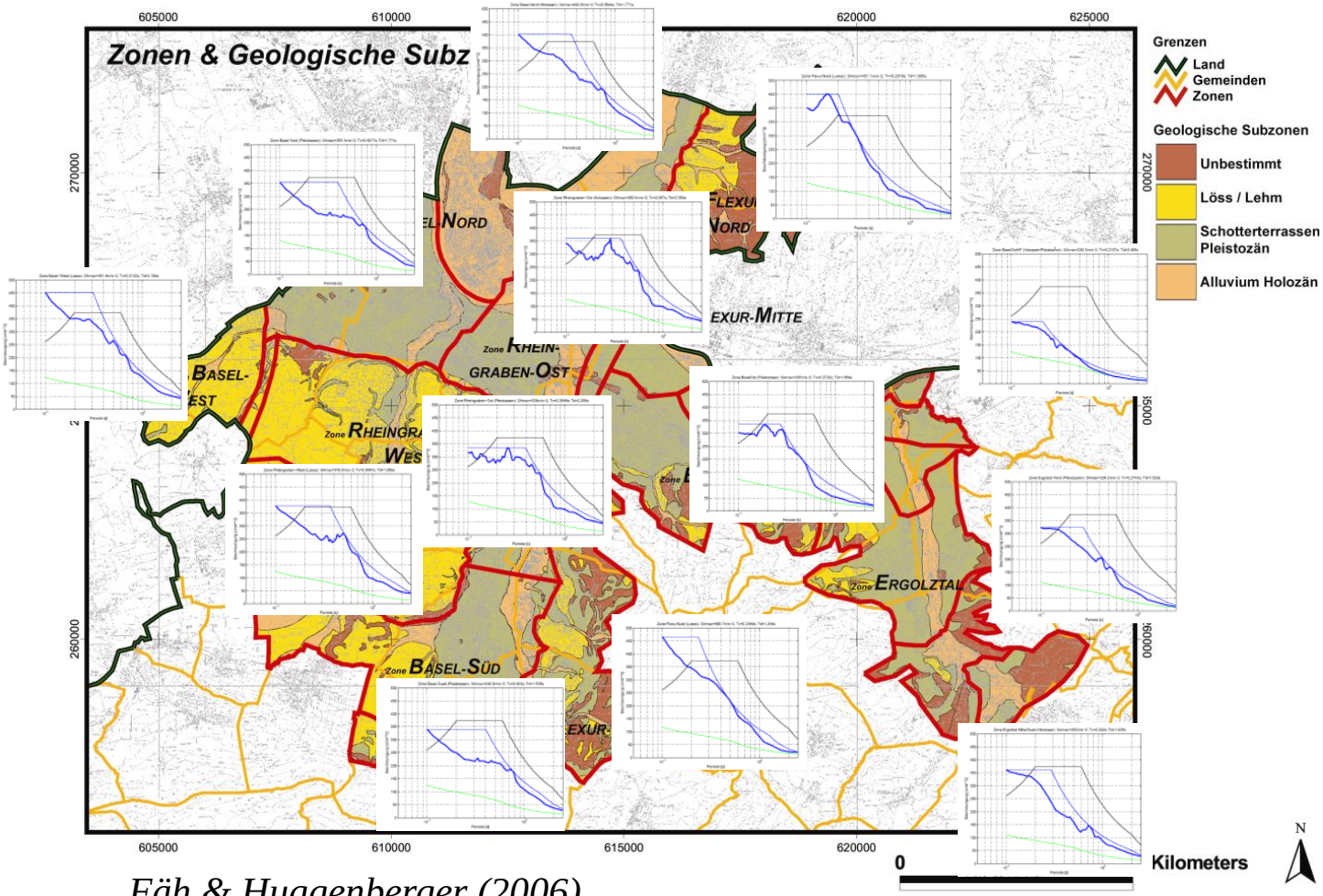




How to make the assessment more site-specific?

Example: microzonation for wider Basel region (2003-2009):

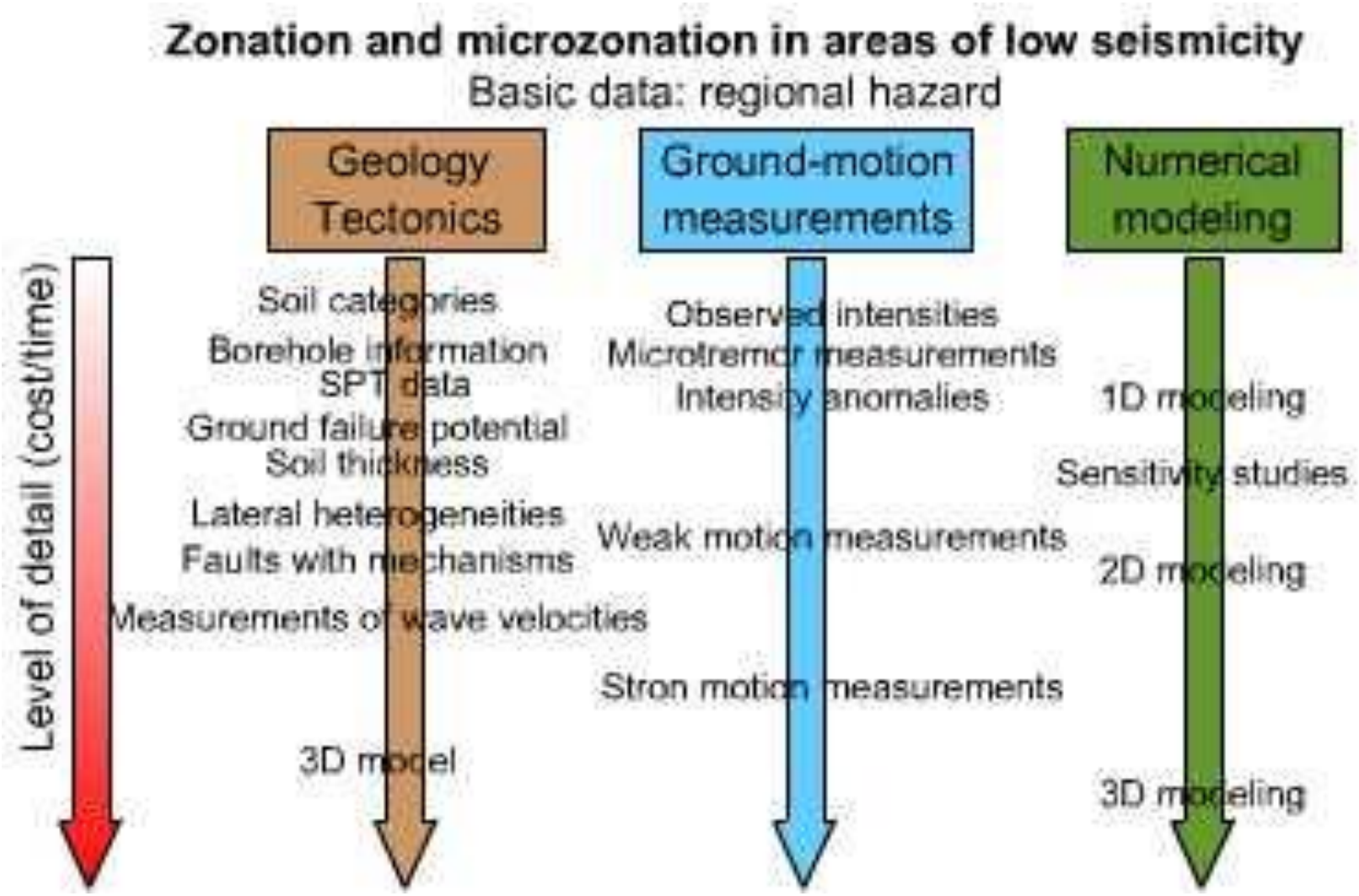
- Design spectra based on ….
- Including conservative choices



Fäh & Huggenberger (2006)

Site Effect Evaluation- Microzonation

Important tool for land-use planing

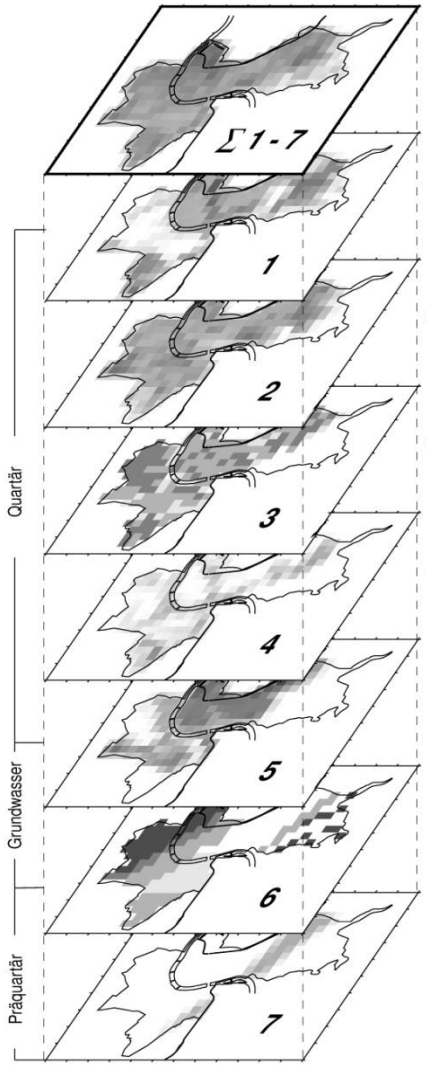


Soil characterization

Important properties of sediments:

- Age
- Composition
- Thickness
- Lateral variations
- Ground water table
- Deep sediments (soft bedrock)
- Rock below the sediments

- Fundamental frequency of resonance
- S-wave velocity profile
- Amplifications as function of frequency
- Non-linear response (and soil/rock failure)

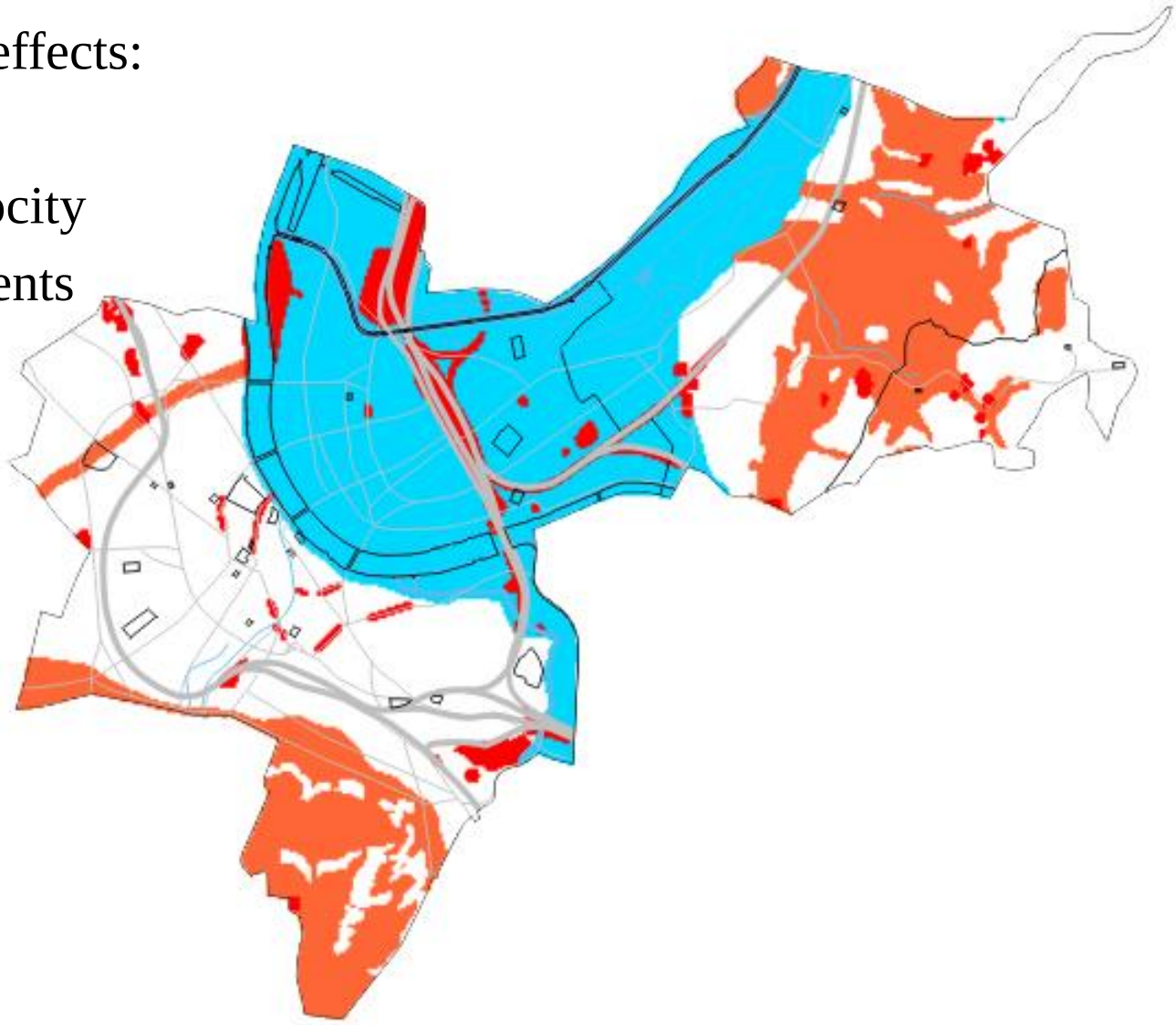


Age / Consolidation

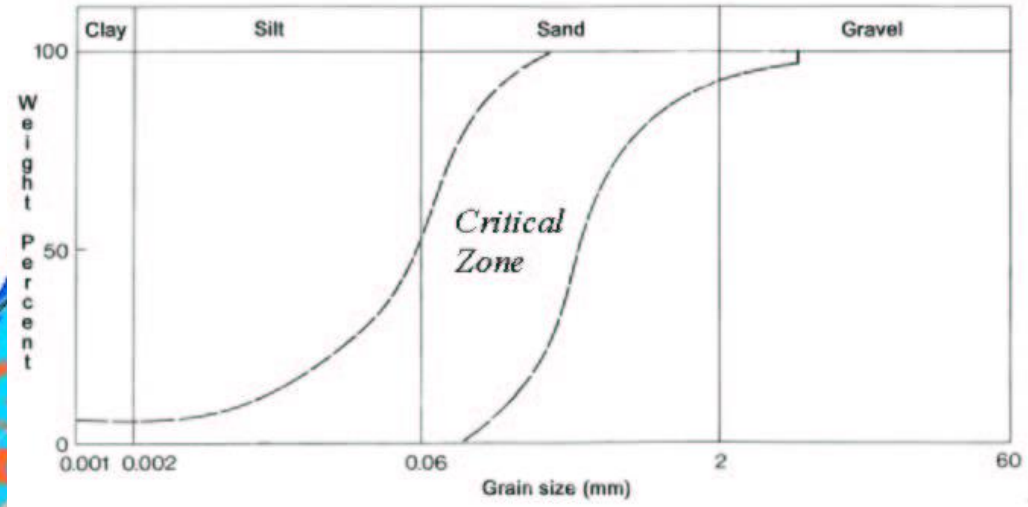
Holocene Sediments / Fill

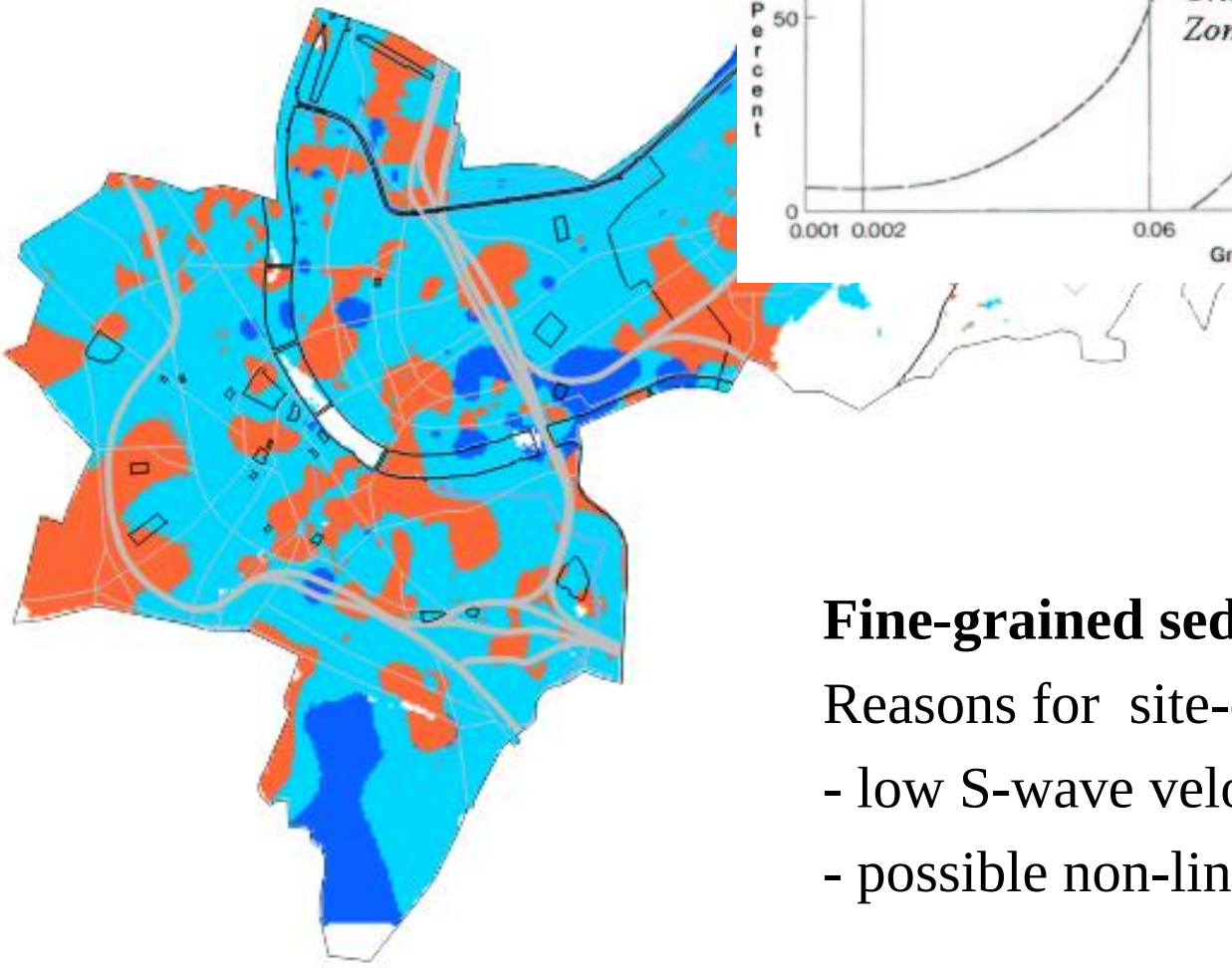
Reasons for site-effects:

- not compacted
- low S-wave velocity
- possible settlements



Composition



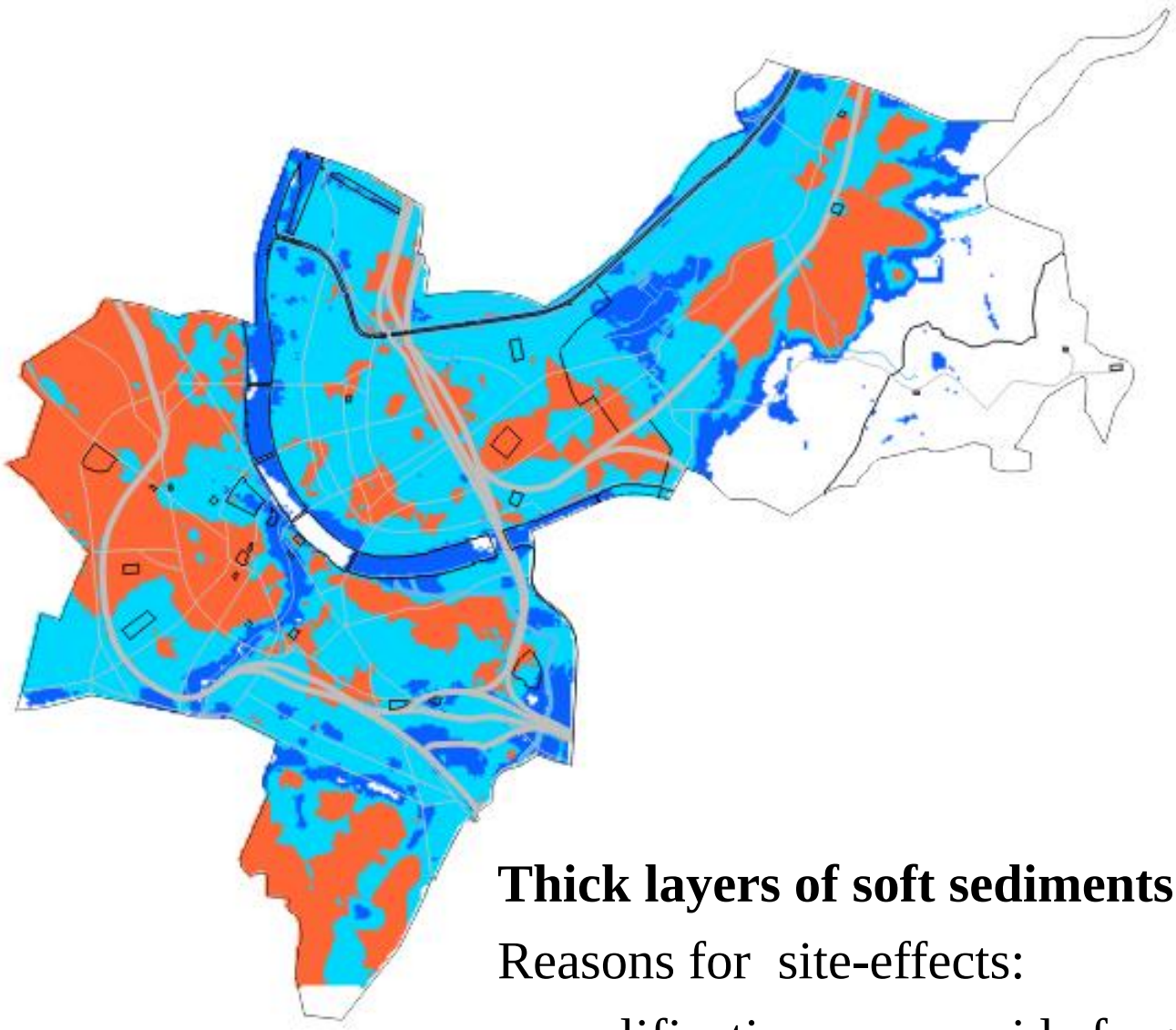


Fine-grained sediments

Reasons for site-effects:

- low S-wave velocity
- possible non-linear behavior

Thickness

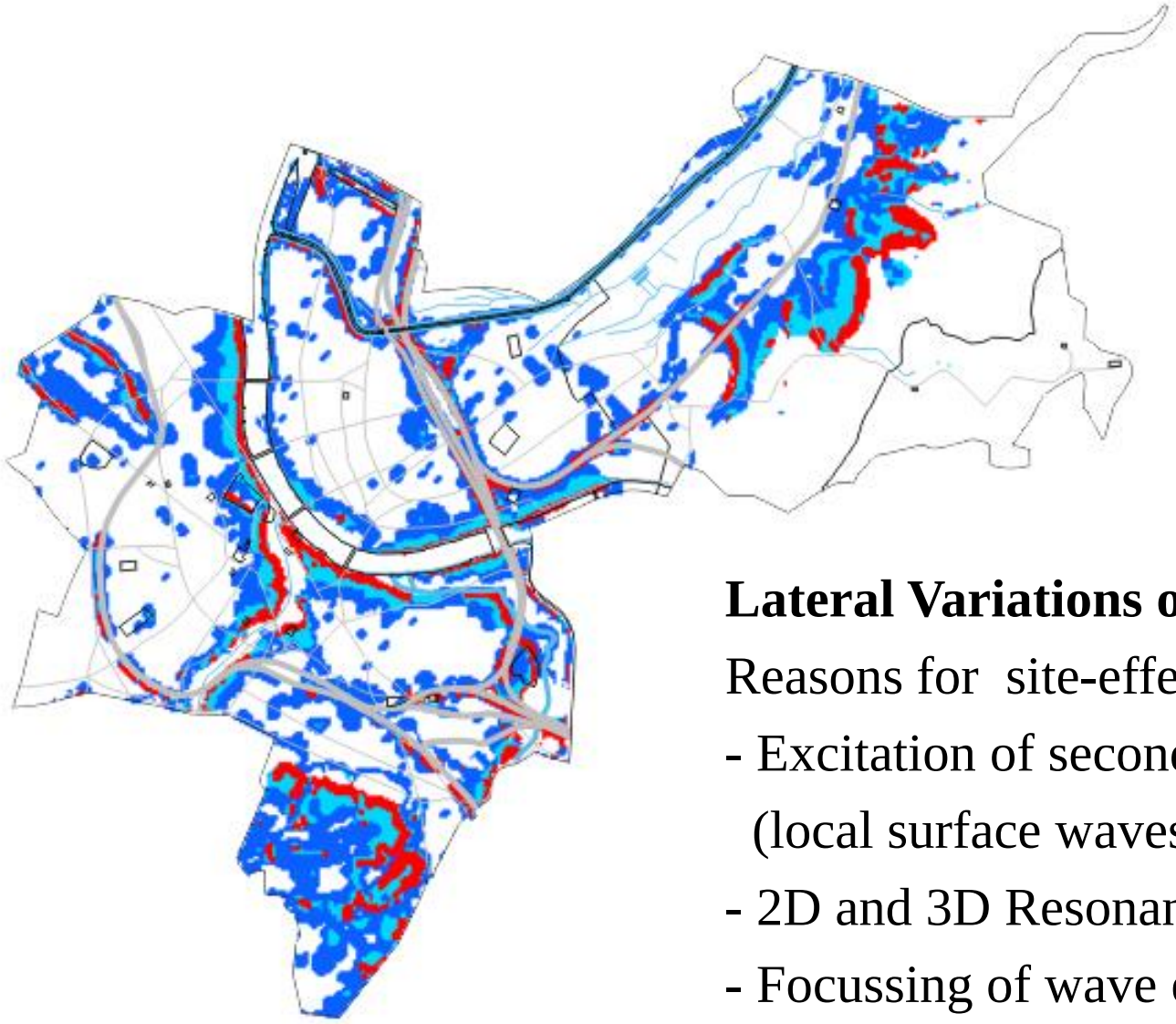


Thick layers of soft sediments

Reasons for site-effects:

- amplification over a wide frequency band

Lateral Variations



Lateral Variations of the soil condition

Reasons for site-effects:

- Excitation of secondary waves (local surface waves)
- 2D and 3D Resonances
- Focussing of wave energy
- Effects of the topography

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Ground-water table

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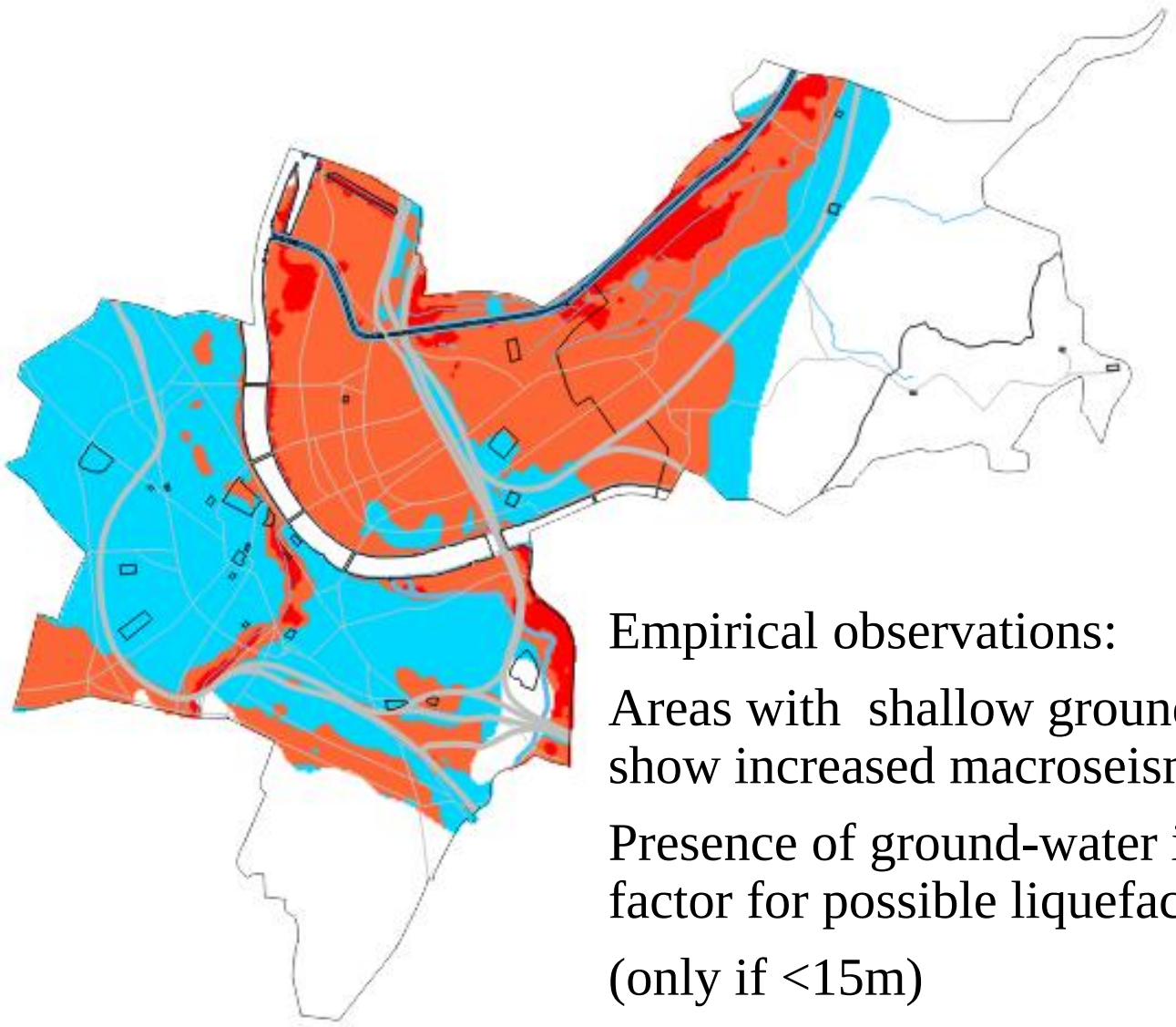

Empirical observations:

Areas with shallow ground-water table show increased macroseismic intensities

Presence of ground-water is an important factor for possible liquefaction

(only if <15m)

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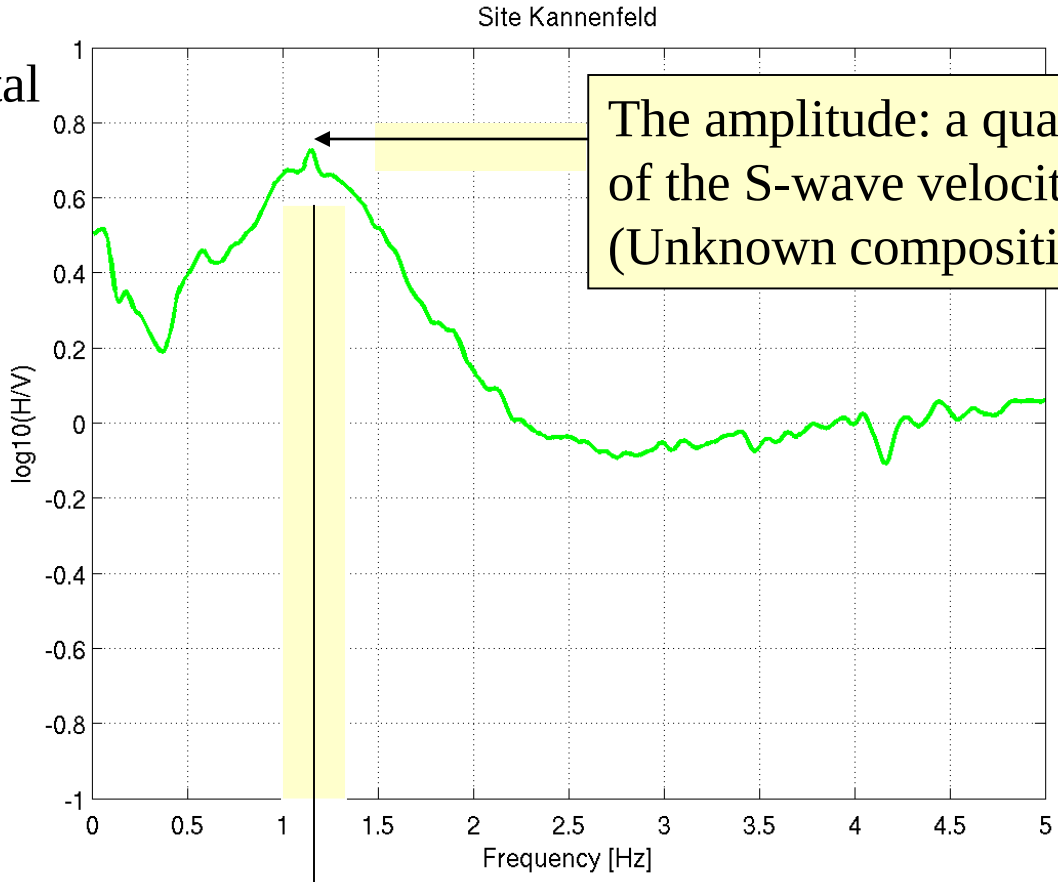
Fundamental frequency of resonance (soft sediment layer over rock halfspace) Ambient vibration H/V spectral ratios

H: FT Horizontal

V: FT Vertical



The amplitude: a qualitative measure of the S-wave velocity contrast (Unknown composition of wavefield)

$f_0=v_s/4h$

Peak is at fundamental frequency $f_0=v_s/4h$ of the sediments

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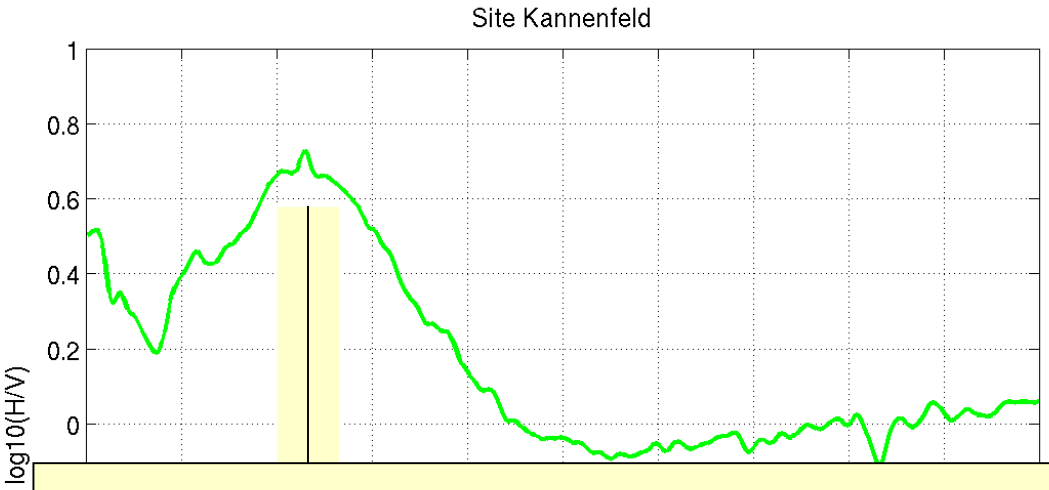
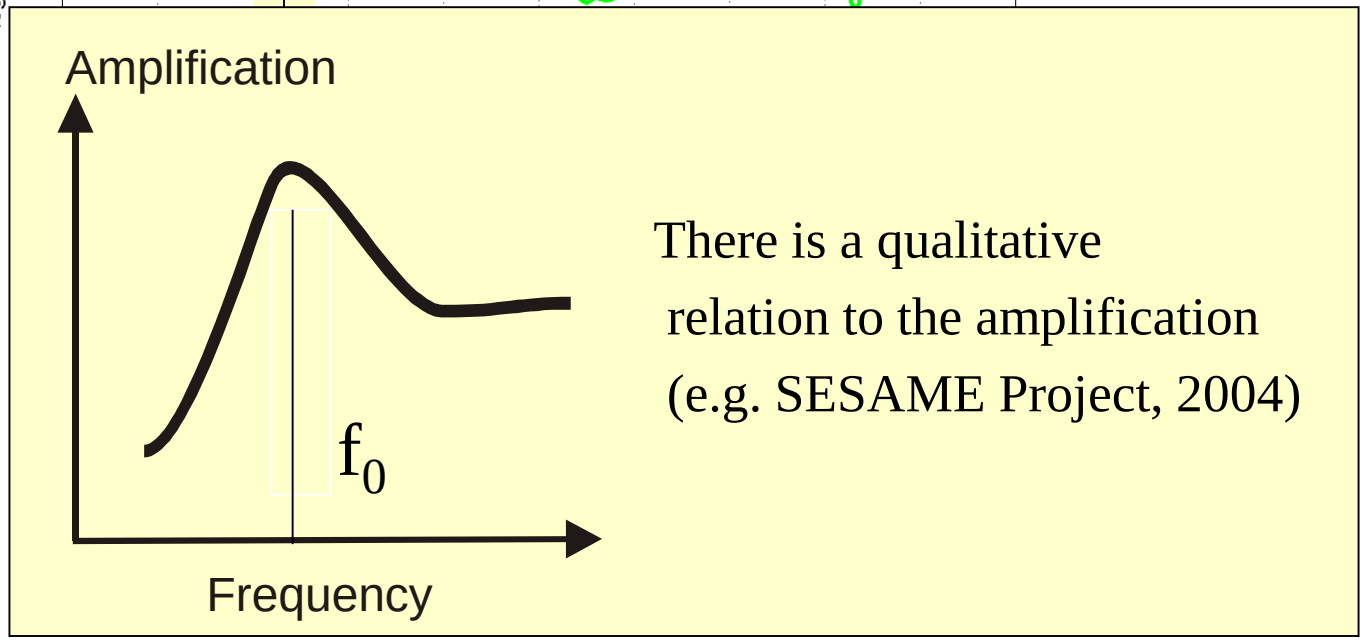


$f_0 = v_s / 4h$



There is a qualitative relation to the amplification (e.g. SESAME Project, 2004)

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Map of the fundamental frequencies

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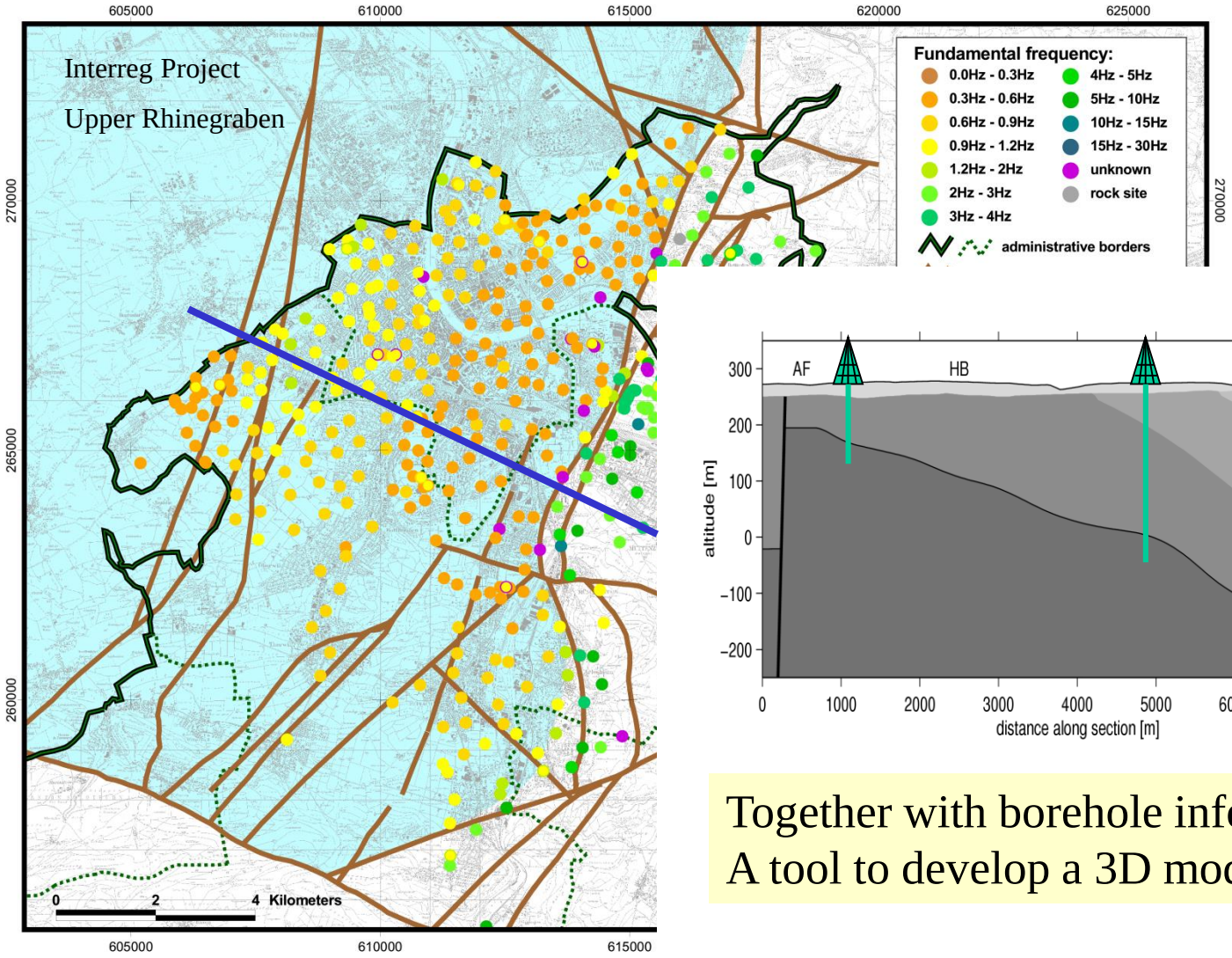

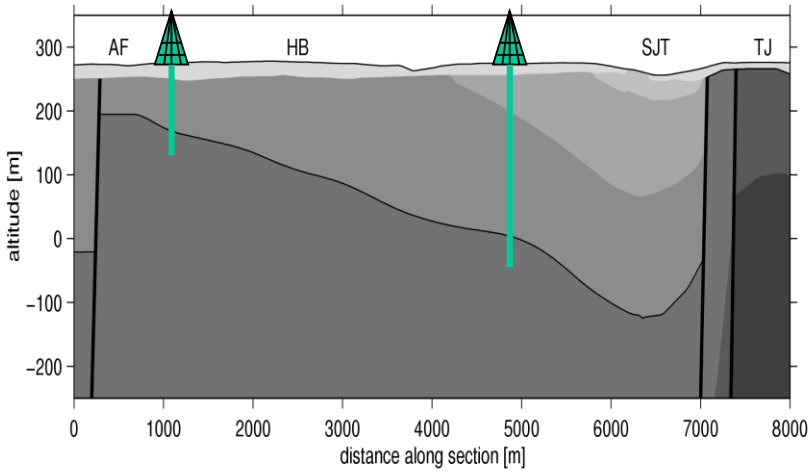

Together with borehole information:
A tool to develop a 3D model

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Amplitude of H/V spectral ratios:

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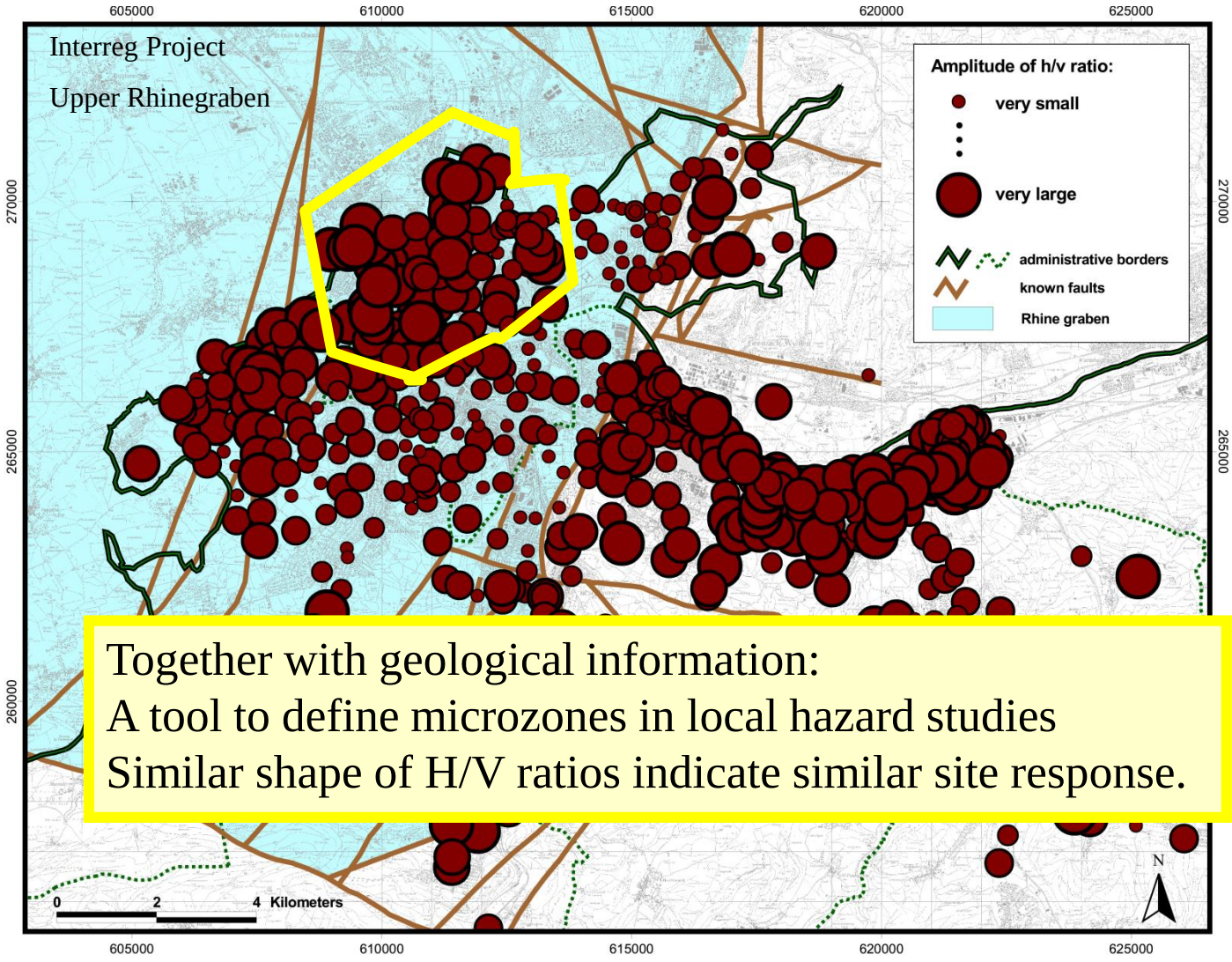
Qualitative map of the S-wave velocity contrast between sediments and bedrock



Together with geological information:
A tool to define microzones in local hazard studies
Similar shape of H/V ratios indicate similar site response.

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Characteristic S-wave velocity profiles

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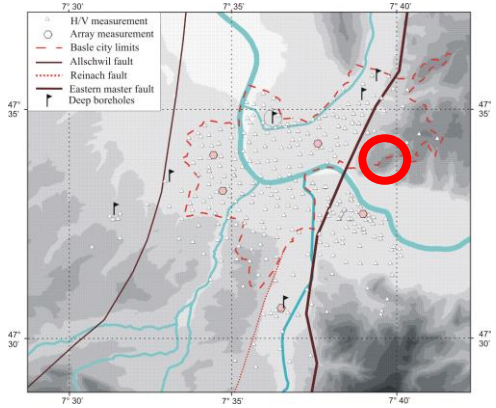
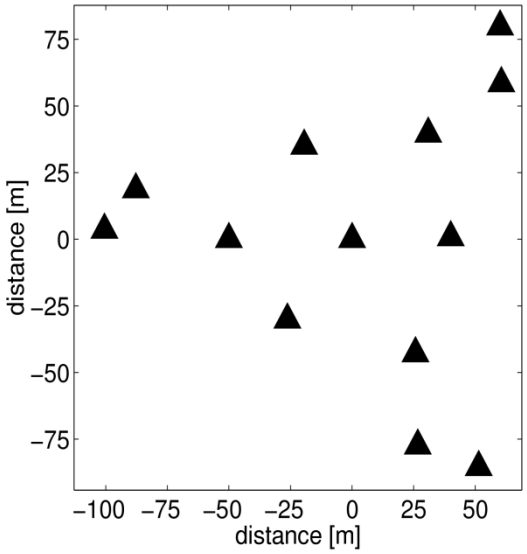
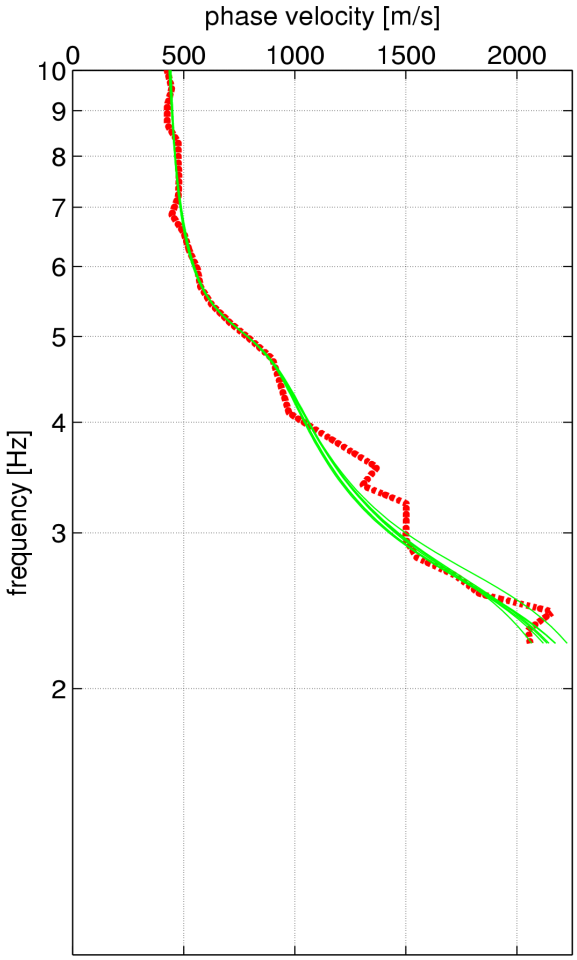


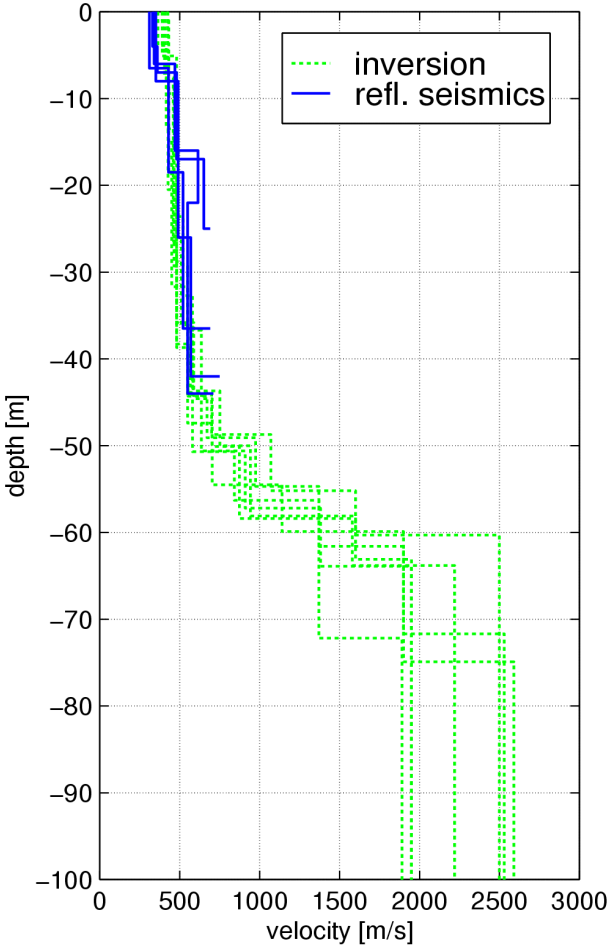
Array geometry



Dispersion curve fundament mode Rayleigh wave



Velocity model

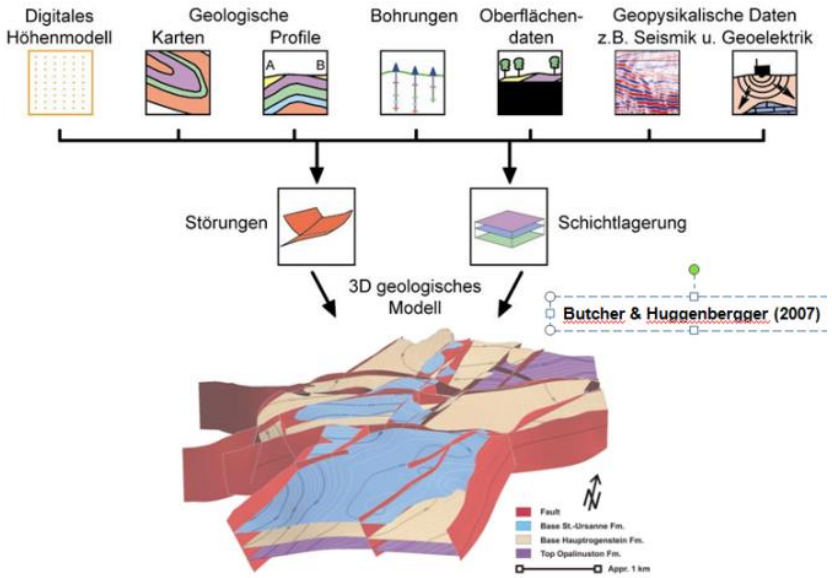


Numerical modeling to estimate the amplification

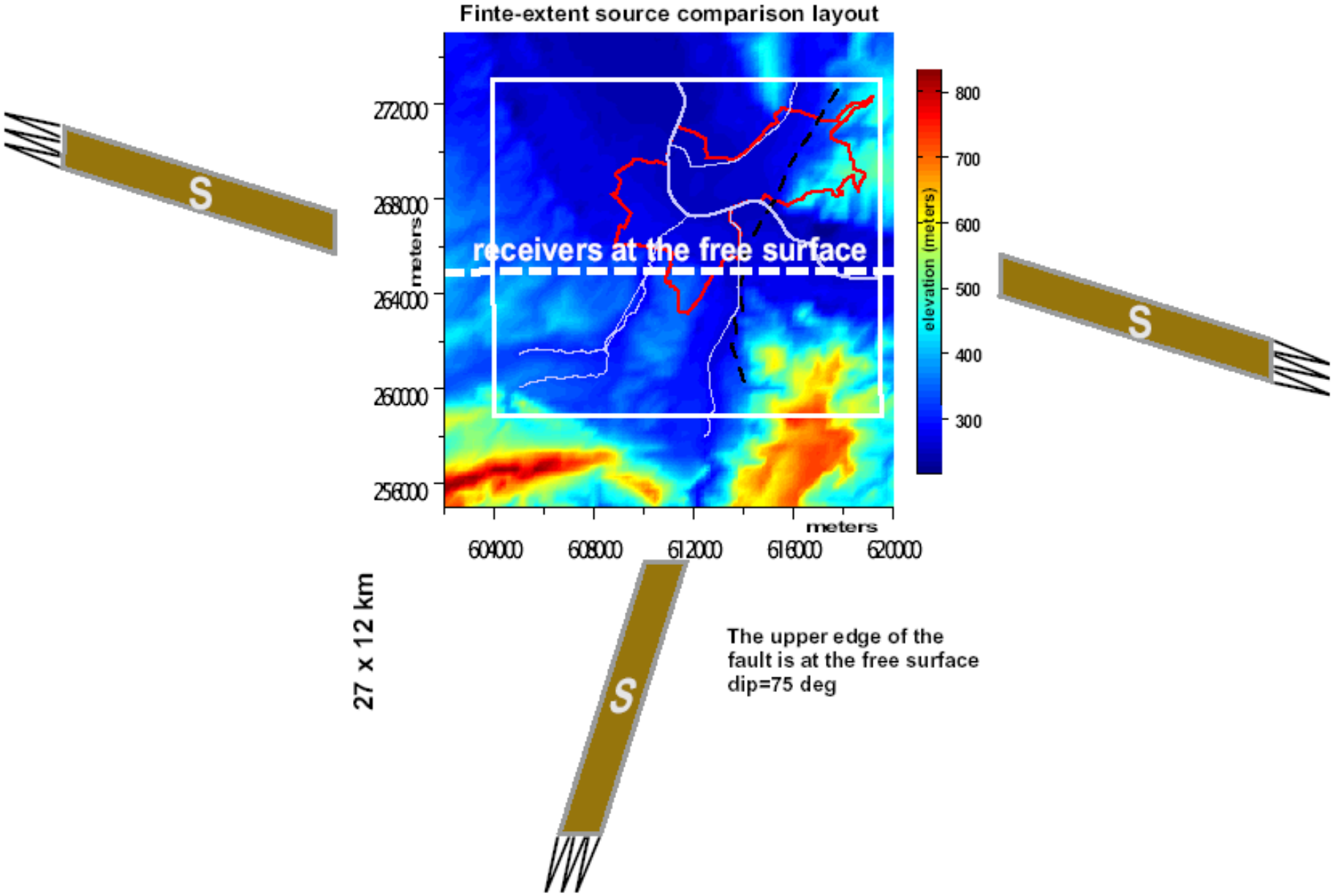
The modeling techniques, we can apply :

- 1D (SH, P-SV), 2D (SH, P-SV), 3D
- elastic, visco-elastic, non-linear material behaviour
- plane waves vertical or obligue incidence, realistic sources (point, extended)

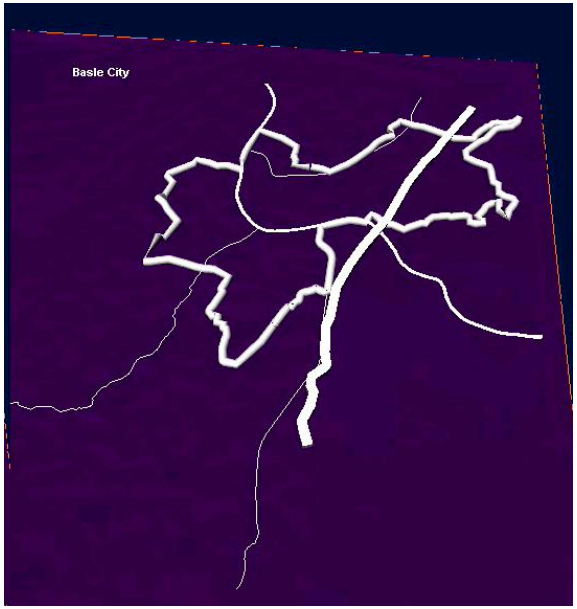
Choose the method according to the available data.
Carefully study of the uncertainties.

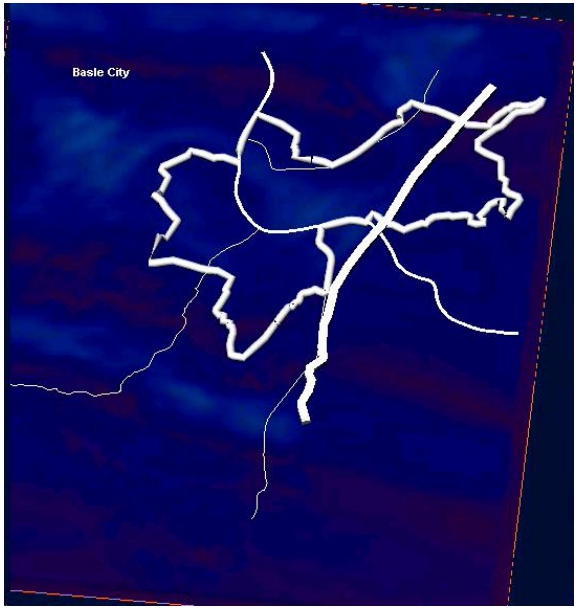


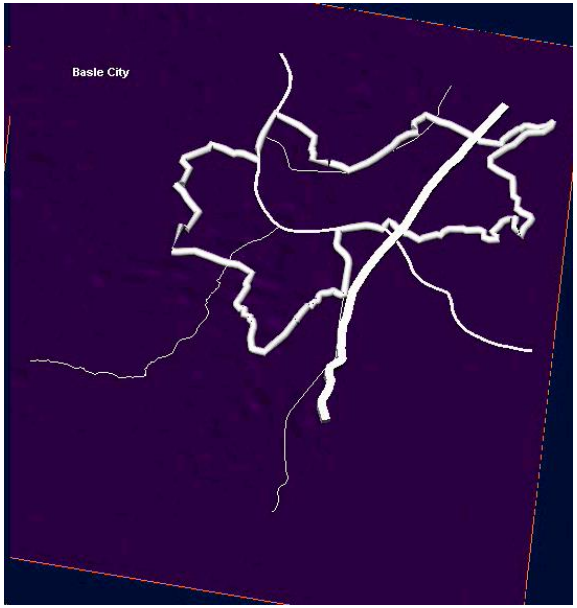
3D Simulations



Numerical modelling (3D)







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Numerical modelling (3D)

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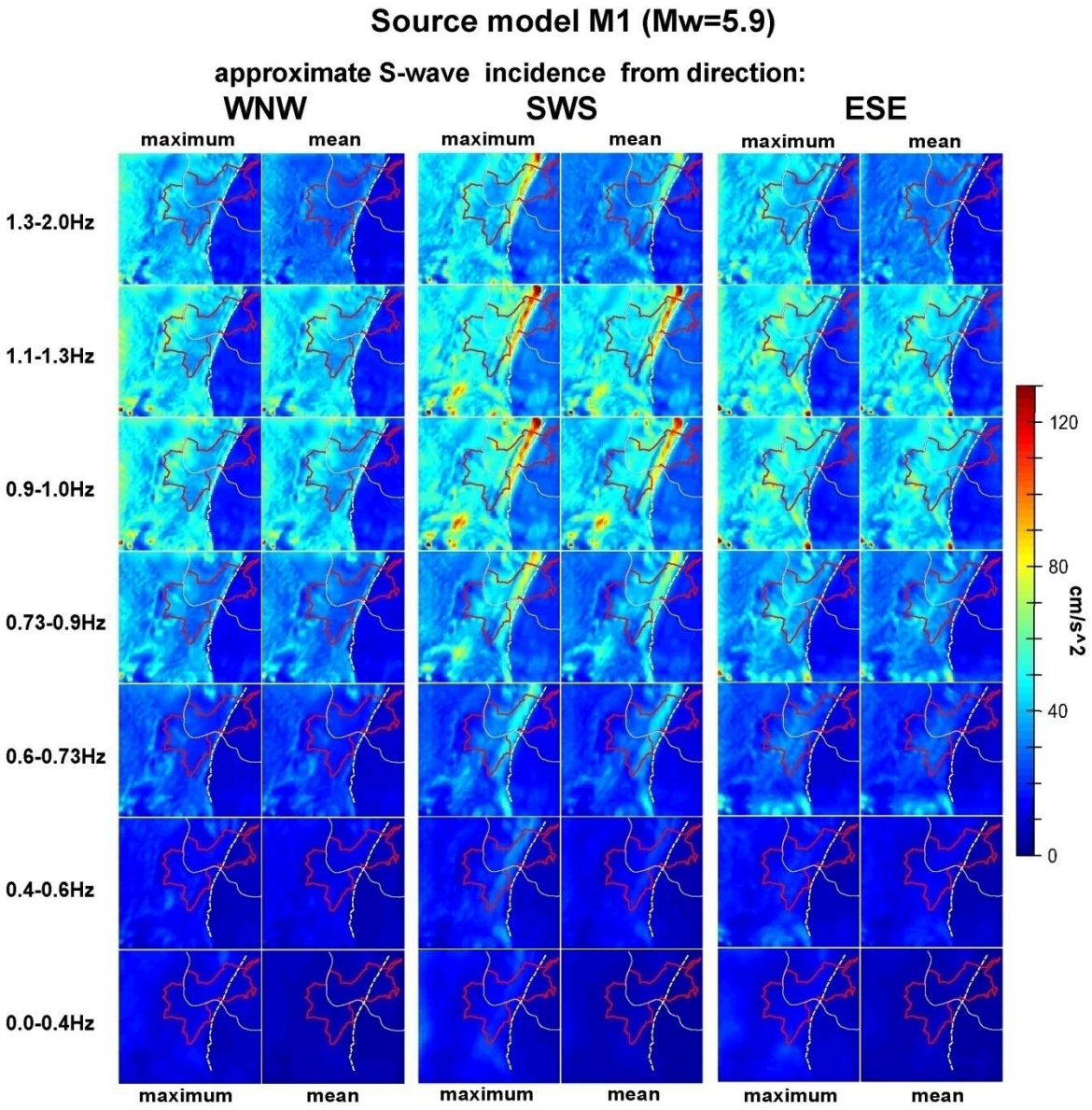
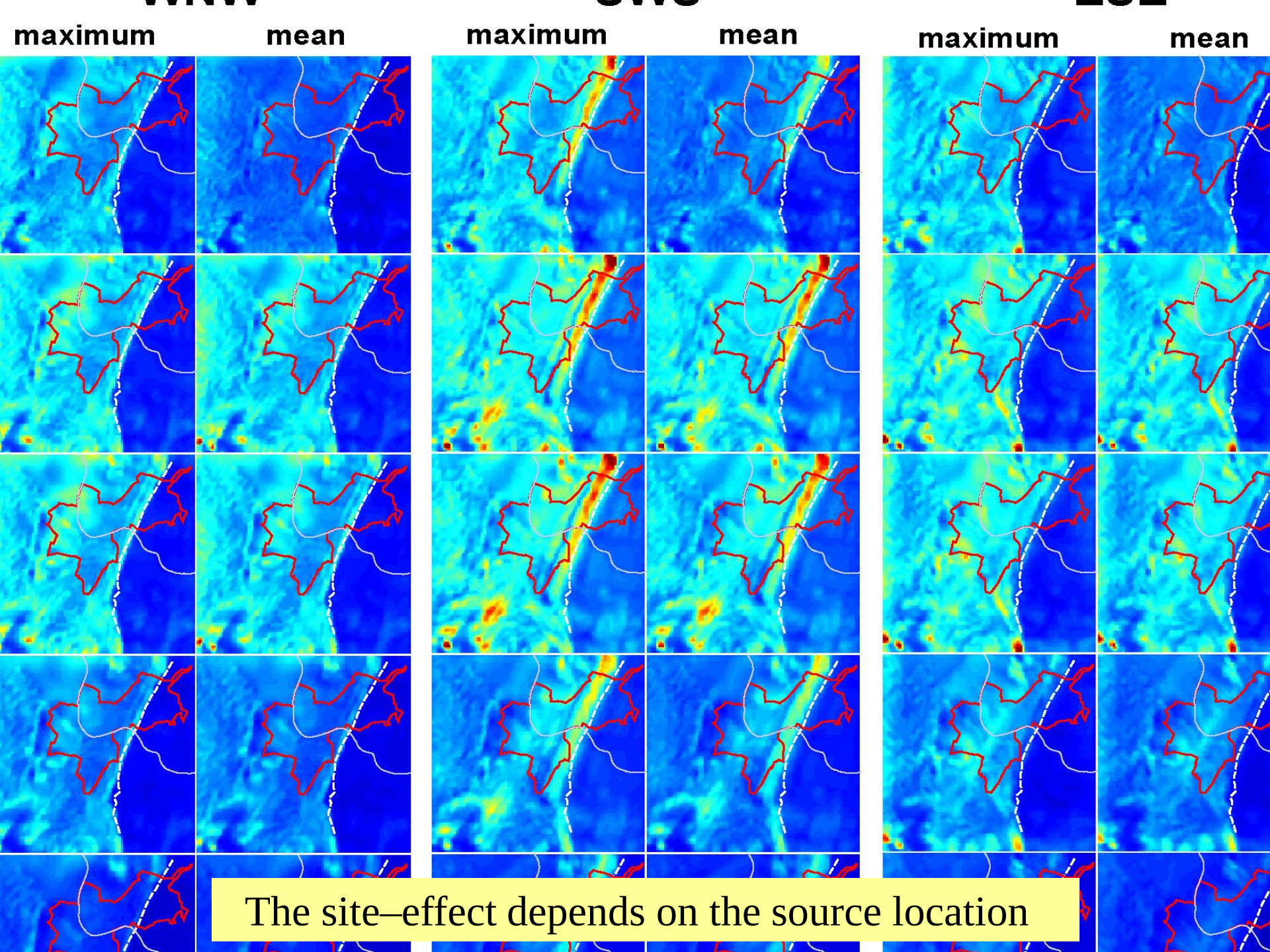


Oprsal et al., 2005

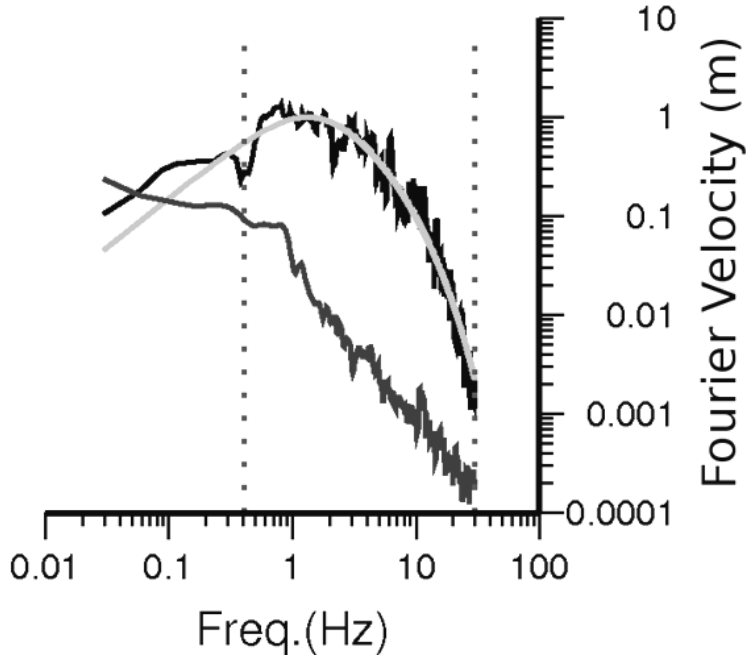


The site–effect depends on the source location

Site-amplification from observations

Estimation of **the source parameters** taking into account consistently site and path effects using spectral modeling of earthquake:

$$\Omega_{ij}(f,r) = \underbrace{\omega \cdot \Omega_i \cdot f_c^{\gamma} / (f_c^{\gamma} + f^{\gamma})}_{\text{Source Spectrum}} \cdot \underbrace{S_{ij}(r) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot t_{ij}^*)}_{\text{Path Effects}} \; \underbrace{A_j(f) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot K_j)}_{\text{Site Effects}}$$



Brune model is applied

Derive source parameters :

Moment magnitude Mw
Corner frequency fc
Stress drop $\Delta\sigma$

(Edwards et al., SRL, 2013)

Site-amplification from observations

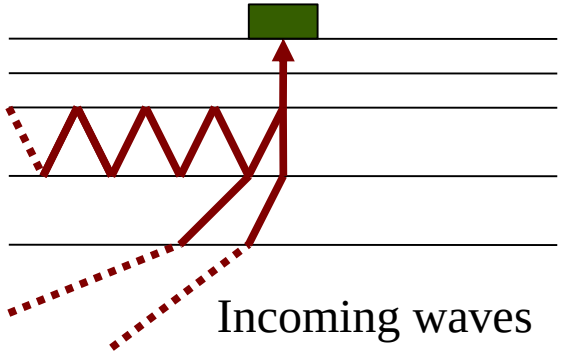
Understanding site-effects

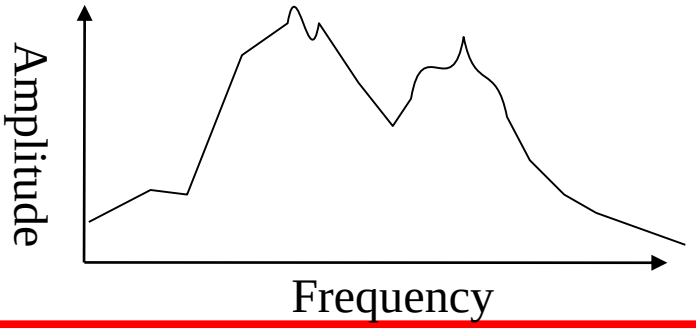
$$\Omega_{ij}(f,r) = \omega \cdot \Omega_i \cdot f_c^{\gamma} / (f_c^{\gamma} + f^{\gamma}) \cdot S_{ij}(r) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot t_{ij}^{*}) \cdot A_j(f) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot K_j)$$

Source Spectrum | Path Effects | Site Effects

Soil/rock in the upper layers:

- Amplification A(f)
- Damping (Kappa)





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Site-amplification from observations

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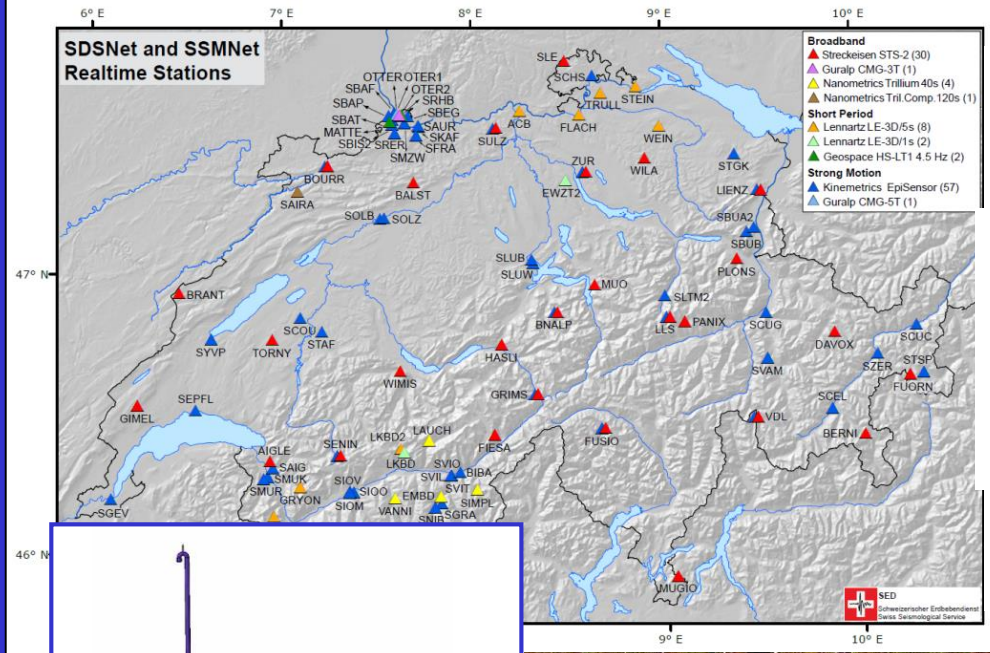
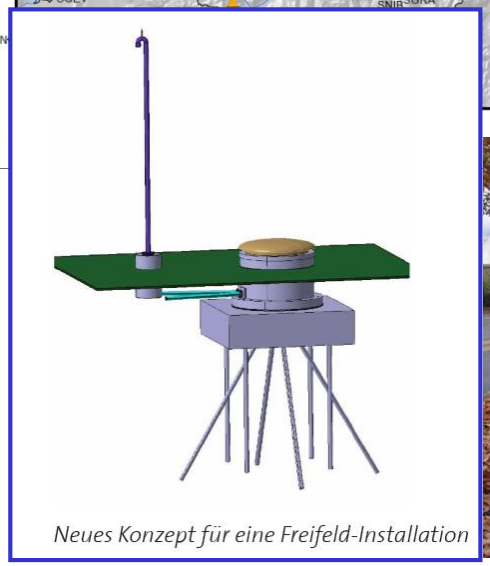
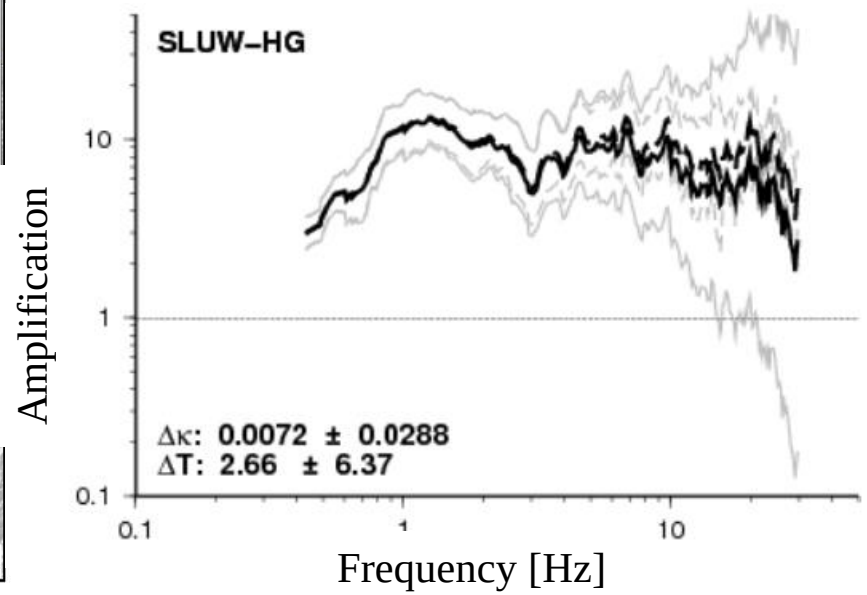
Automatic determination of site-specific empirical amplification for all seismic stations relative to the reference bedrock profile.



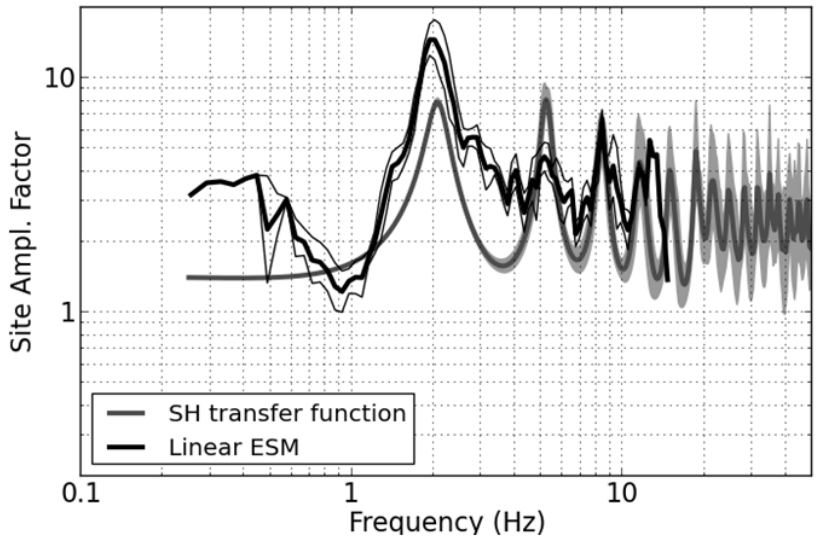




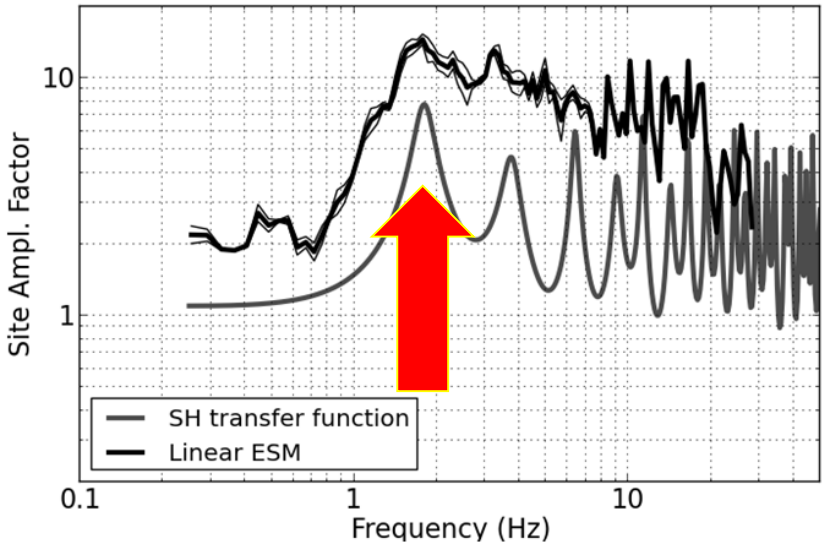
Site-amplification from observations

Derive features of the stations by comparison with computed 1D SH-wave amplification from measured velocity profiles

Simple 1D response at Lausanne EPFL site



Edge-generated surface waves at Visp site



Vs30~200 m/s

Michel et al. (2014)

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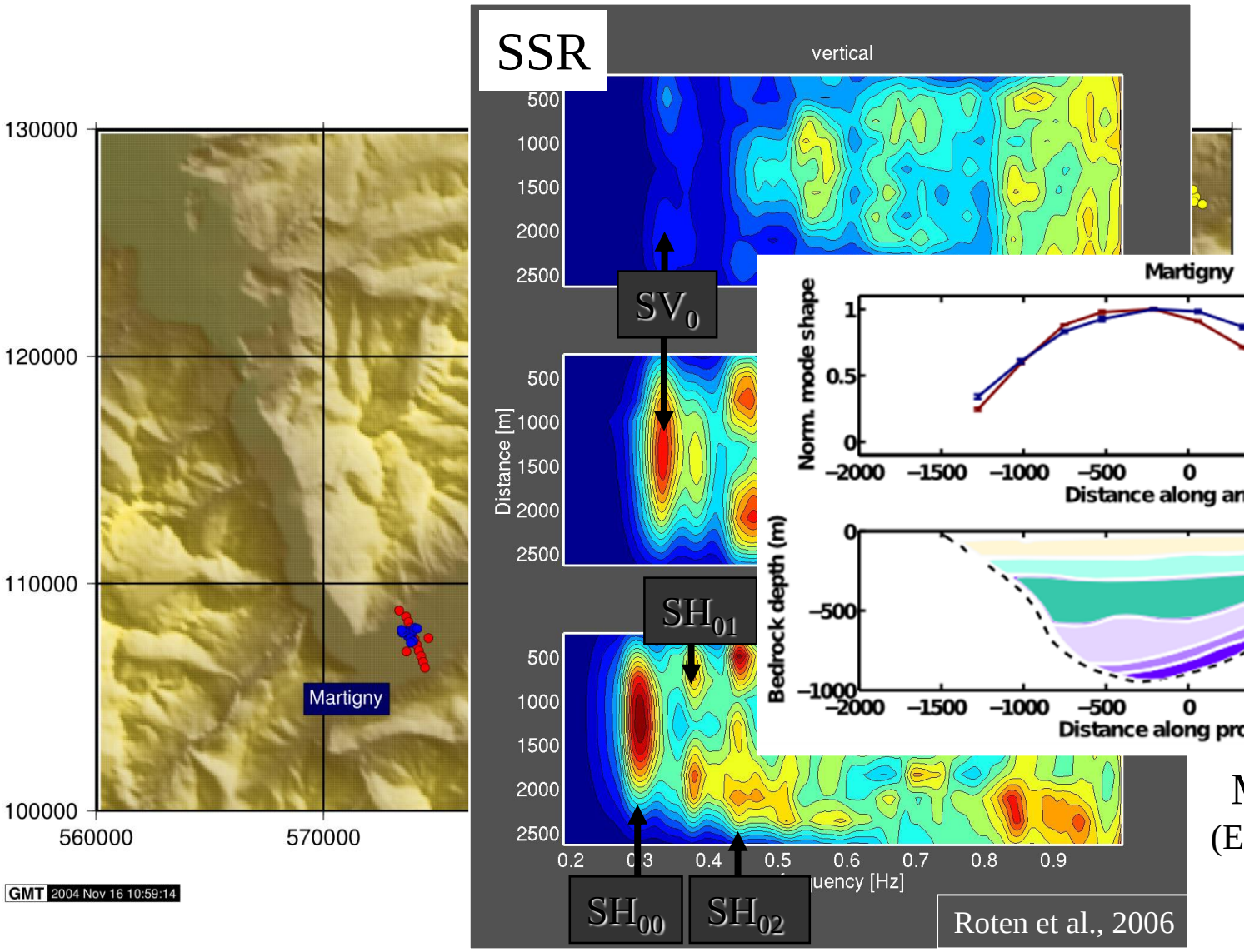
Identification of 2D resonances in Alpine valleys



Modes shapes
(Ermert et al., 2013)

Roten et al., 2006

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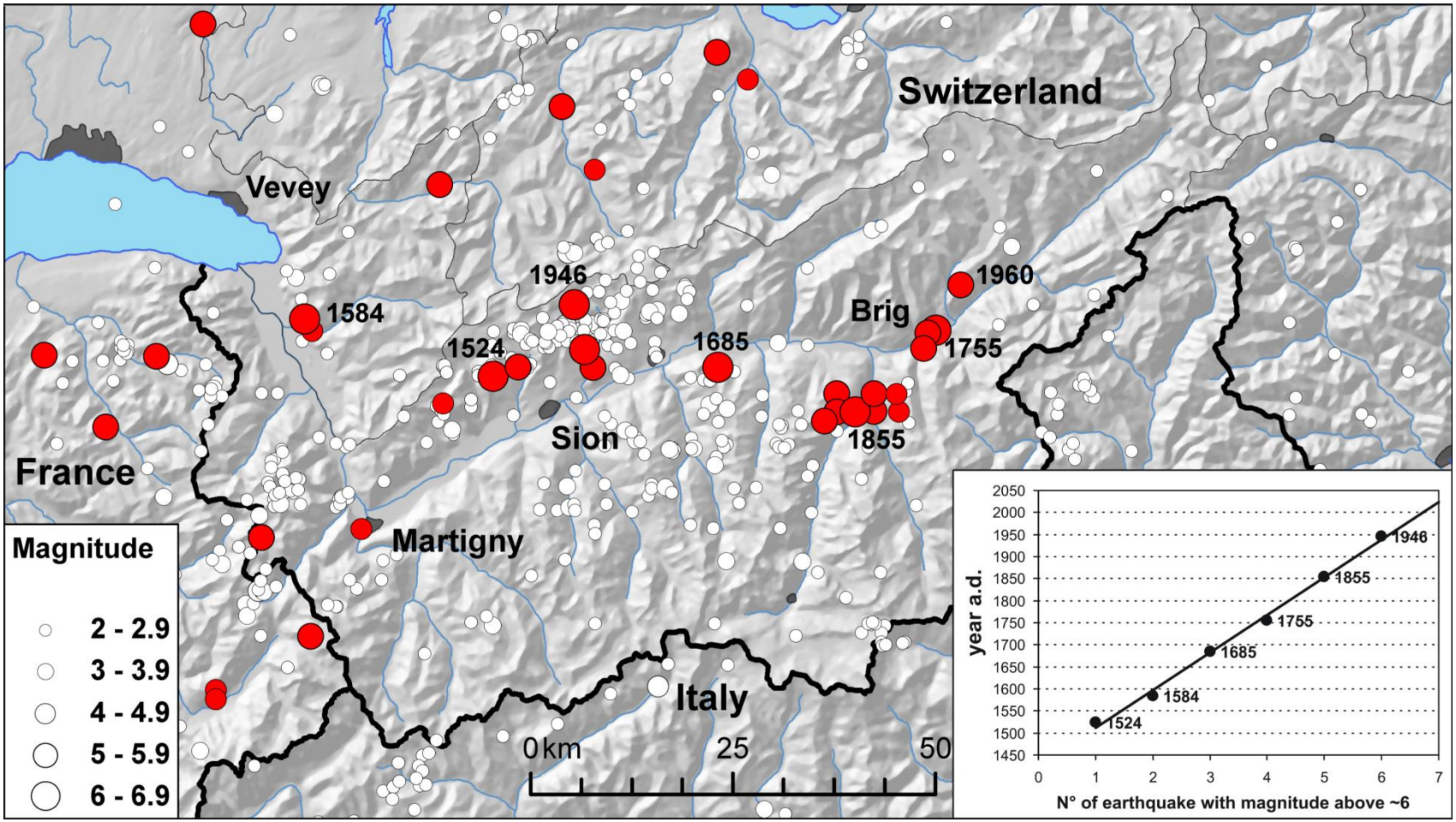
Earthquakes in Valais (Switzerland)



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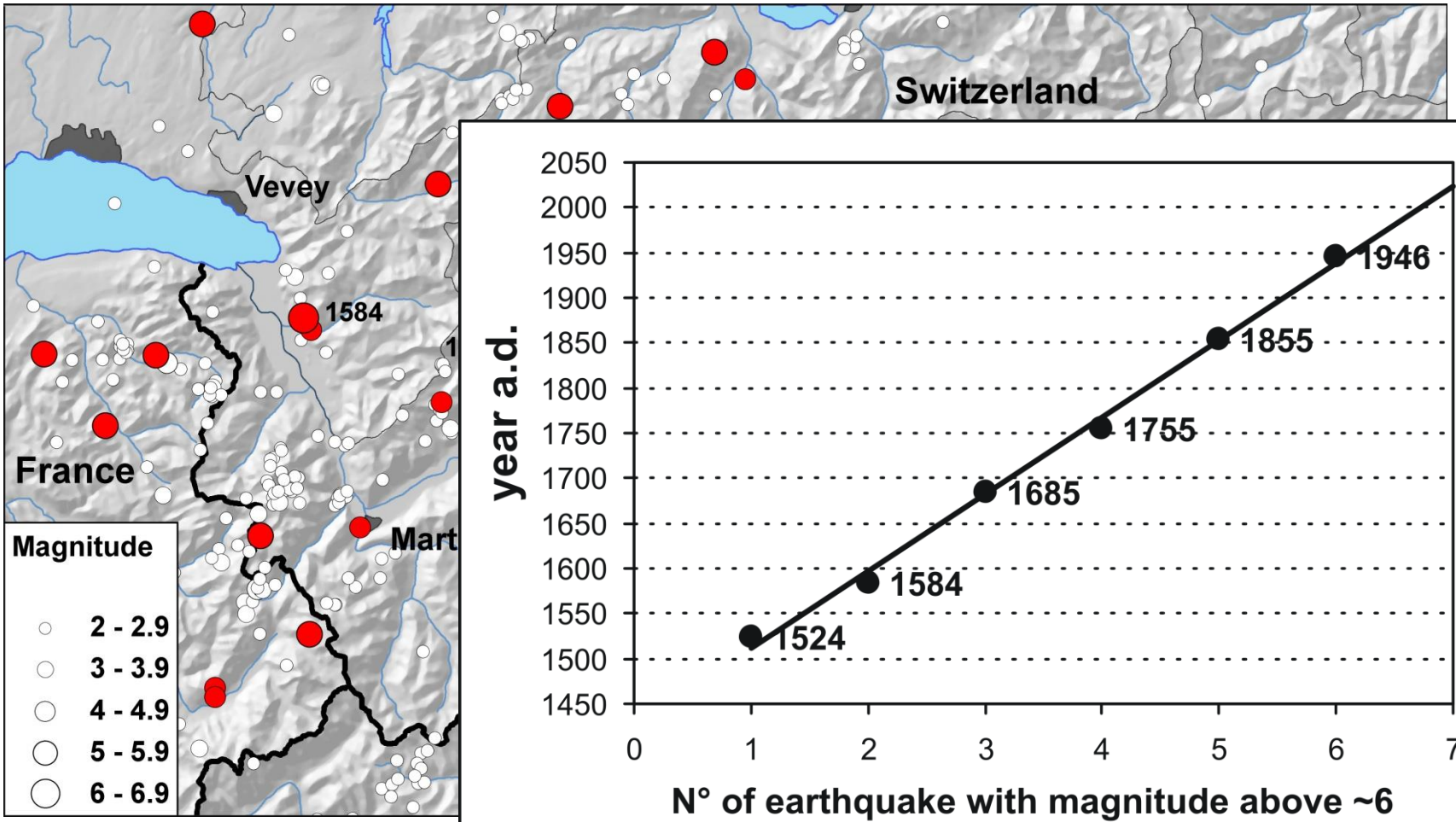
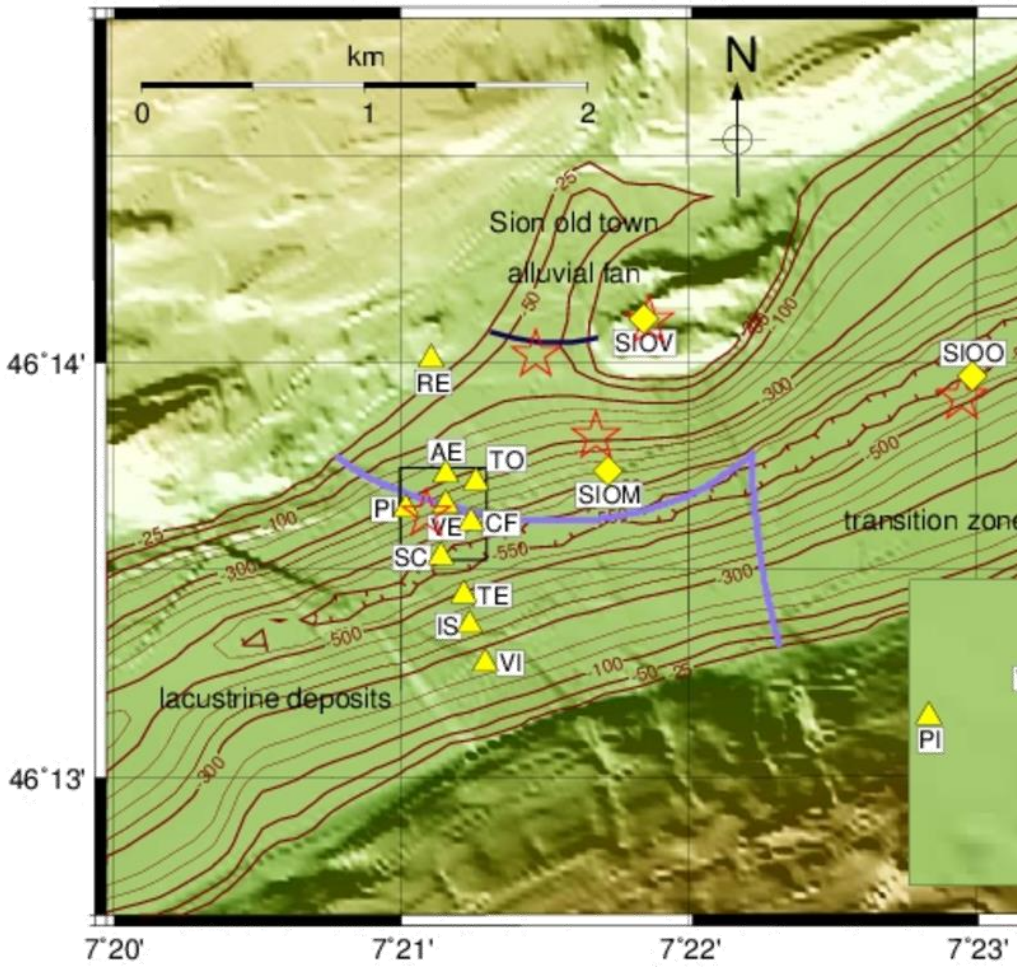
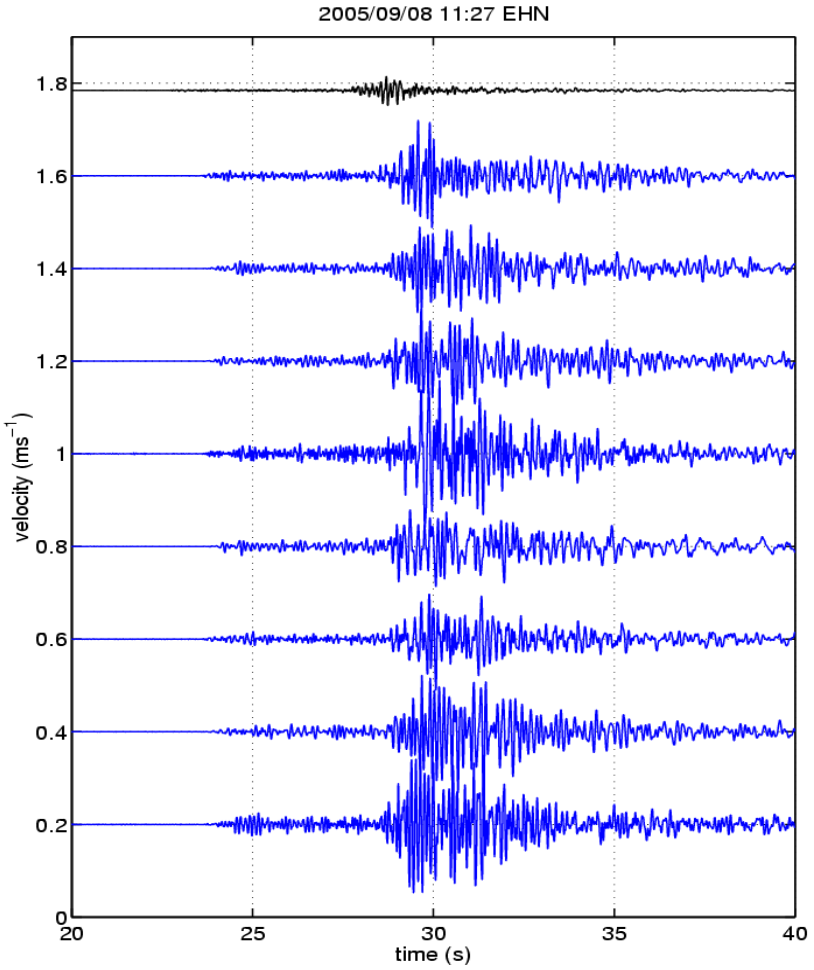


Variability of Ground Motion

Observed site-effects at Sion

(Earthquake of September, 8, 2005 at Vallorcine (Mw=4.5))





Roten et al. (2008)

Variability of Ground Motion

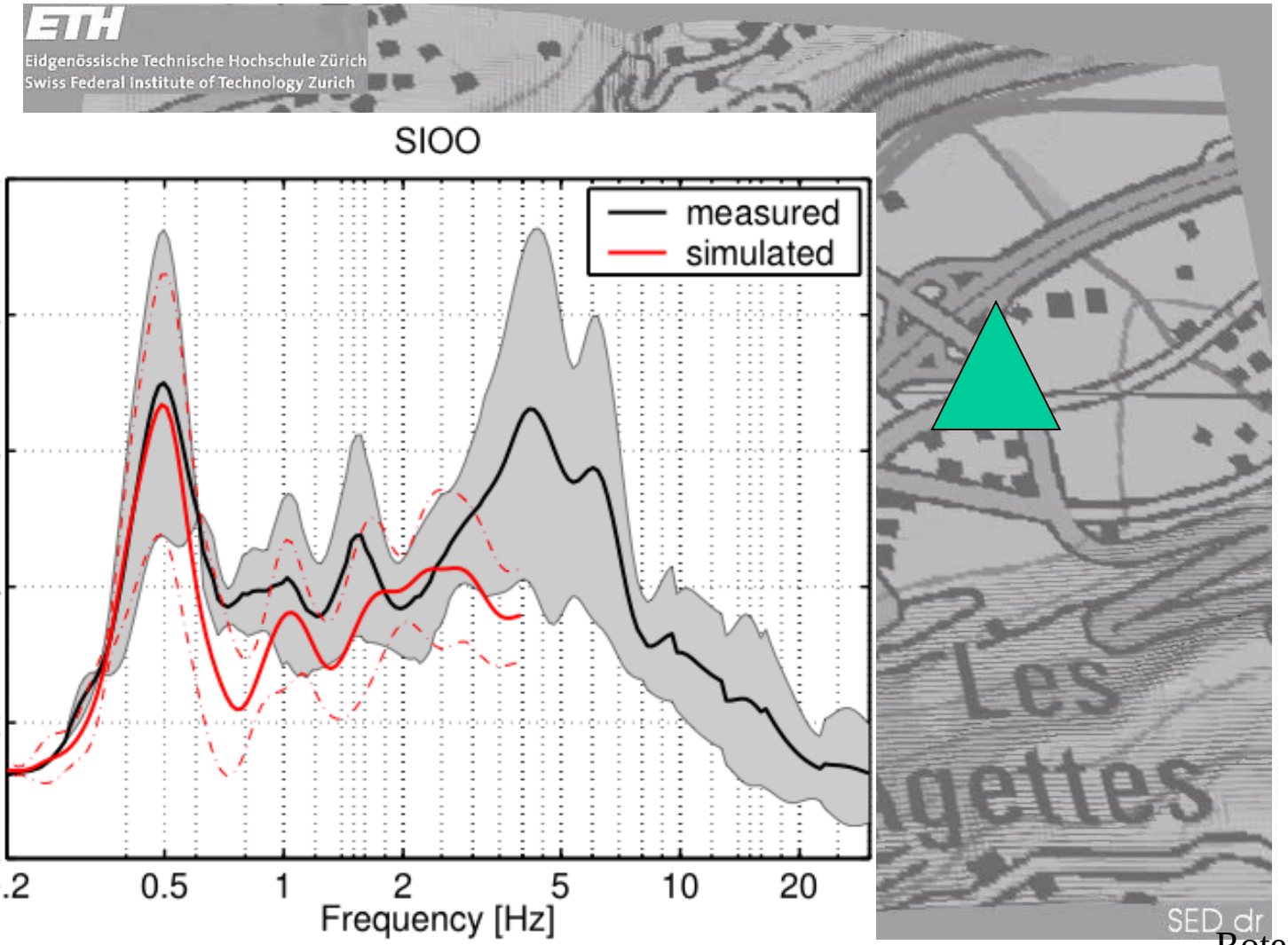
Modelled site-effects at Sion

(Earthquake of September, 8, 2005 at Vallorcine (Mw=4.5))

Variability of Ground Motion

Modelled site-effects at Sion

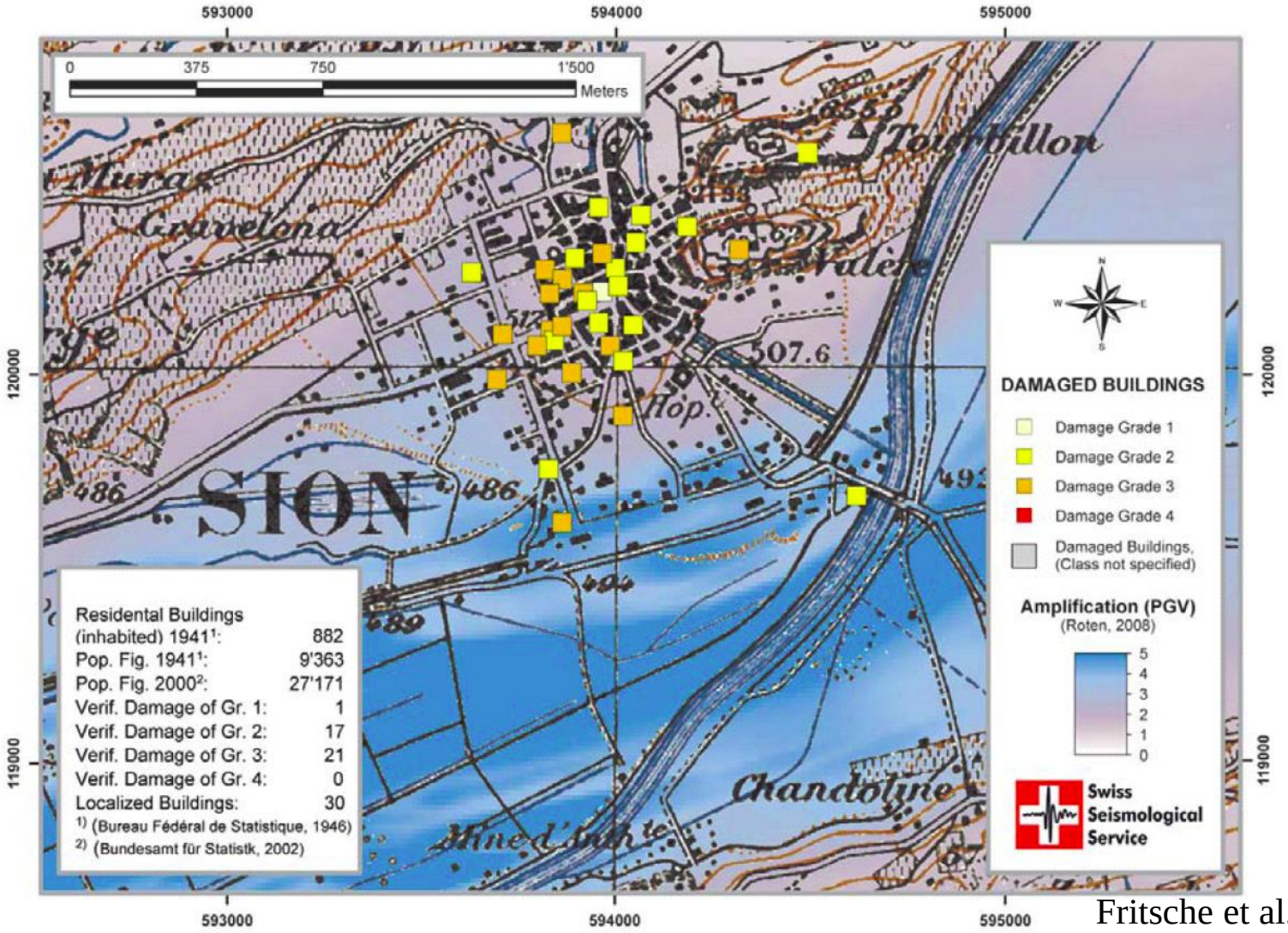
(Earthquake of September, 8, 2005 at Vallorcine (Mw=4.5))



Roten et al. (2008)

Variability of Ground Motion

Earthquake of January, 25, 1946 at Sion



Fritsche et al. (2009)

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Earthquakes with

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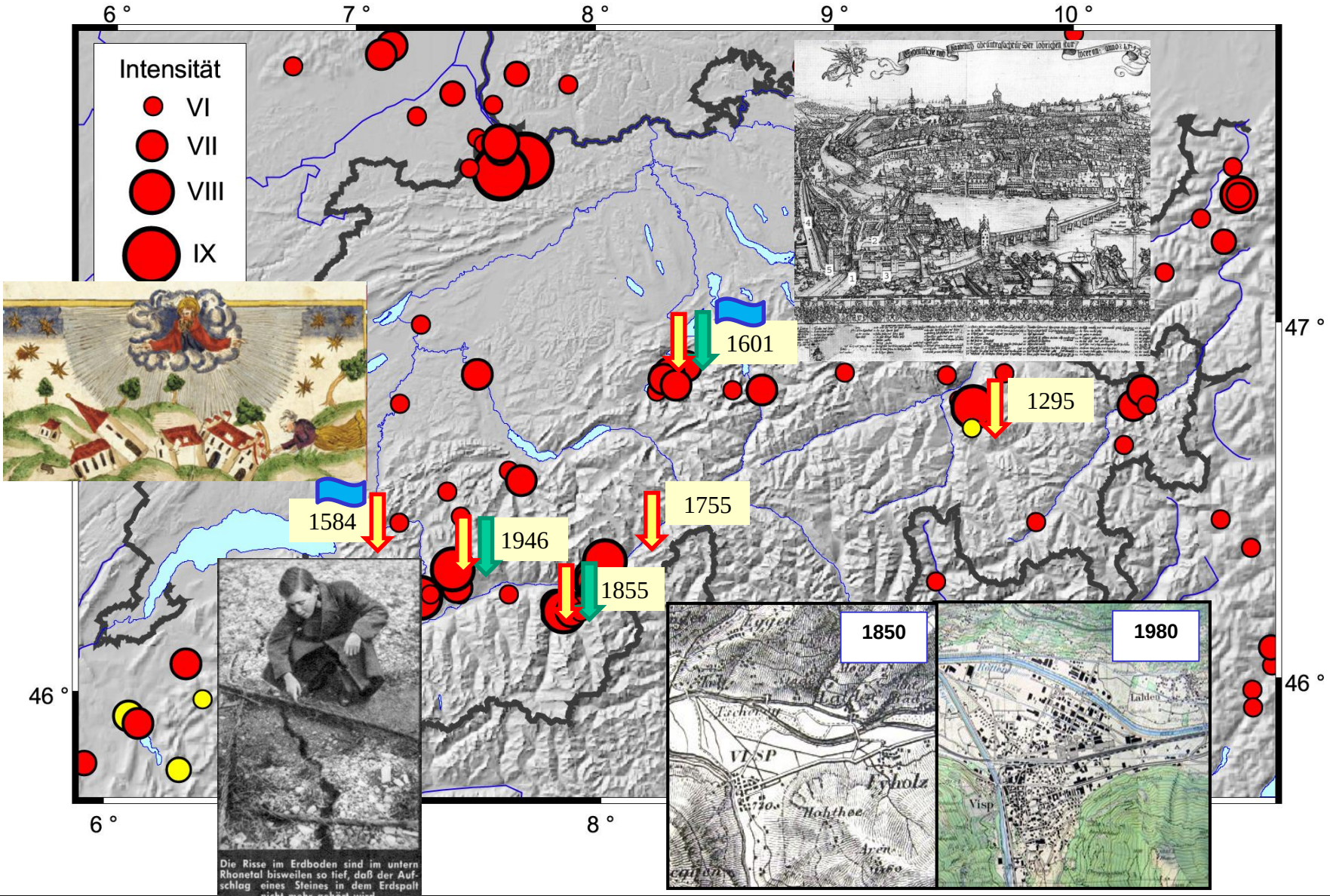
induced soil liquefaction ↓ landslides ↓ and tsunami ≈



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Aigle 1584 (Mw=5.9)

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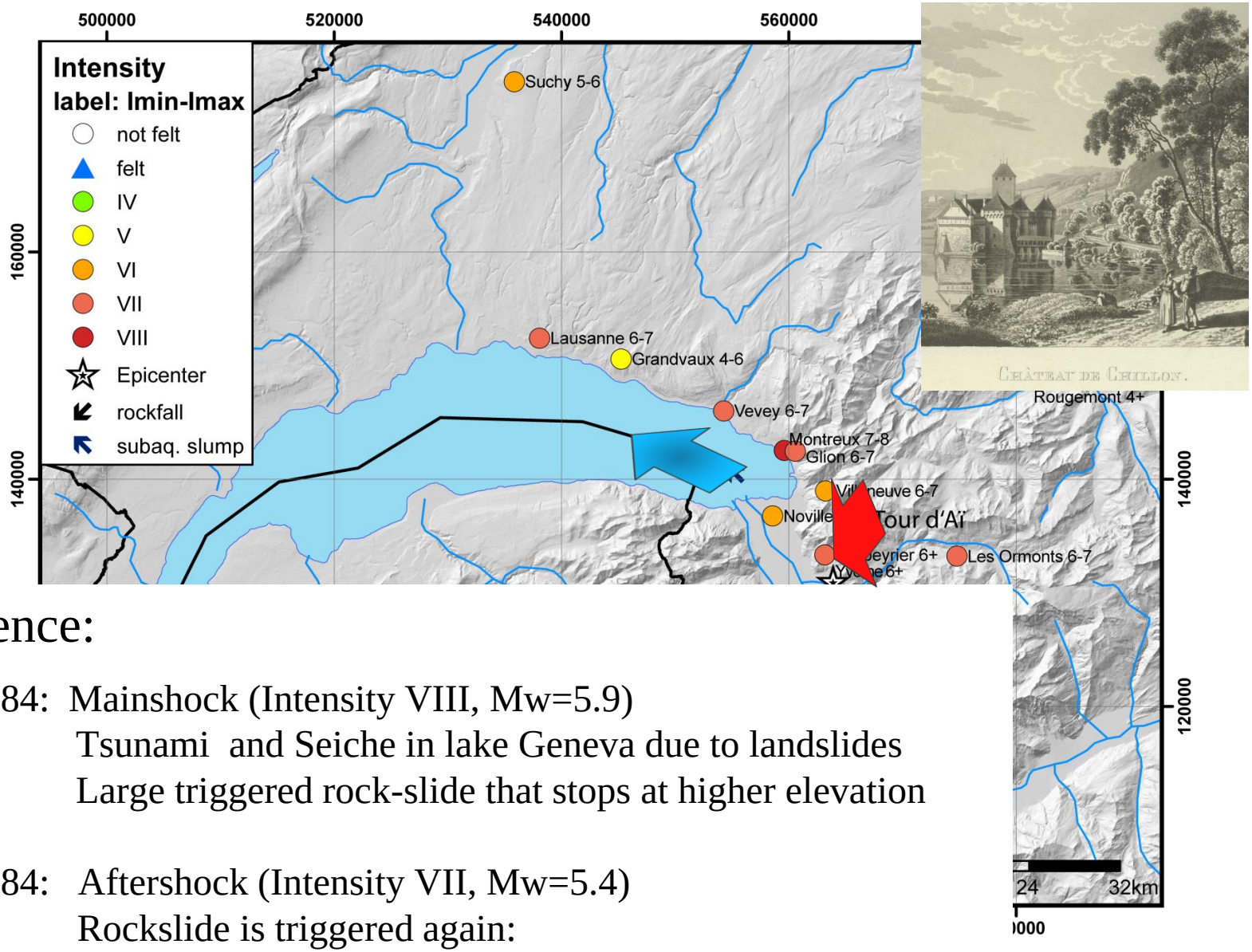


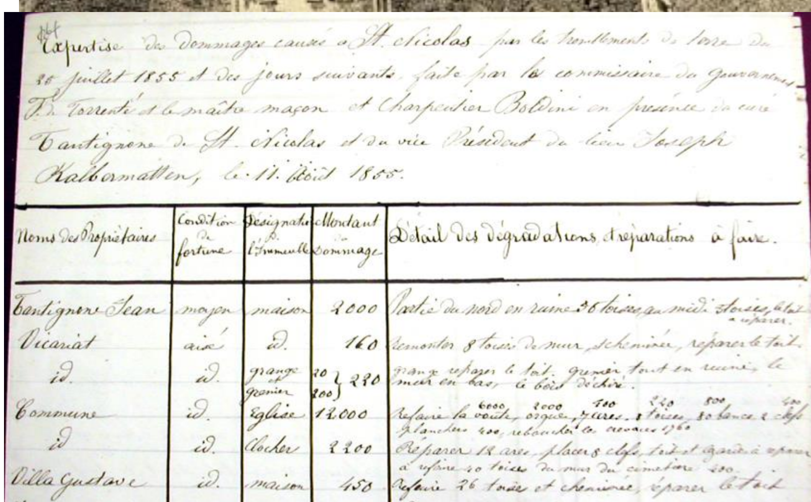
Sequence:

11.3.1584: Mainshock (Intensity VIII, Mw=5.9)
Tsunami and Seiche in lake Geneva due to landslides
Large triggered rock-slide that stops at higher elevation

14.3.1584: Aftershock (Intensity VII, Mw=5.4)
Rockslide is triggered again:
Destruction of Corbeyrier and Yvorne

Schwarz et al. (2014)

Visp 1855 (Mw 6.2): Documentation



Expertise des Dommages causé à St. Nicolas par les tremblements de terre du 25 juillet 1855 et des jours suivants, faite par le commissaire du gouvernement J. de Torrenté et le maître maçon et Charpentier Boldini en présence du curé Tantignone de St. Nicolas et du vice Président du [illegible] Joseph Kalbermatten, le 11. Août 1855.

Noms des Propriétaires	Condition de fortune	Désignation de l'Immeuble	Montant du Dommage	Détail des dégradations et réparations à faire.
Tantignone Jean	maçon	maison	2000	Partie du nord en ruine 36 toises, au midi 3 toises, le toit à réparer.
Vicariat	aisé	id.	160	Remonter 8 toises de mur, 3 cheminée, réparer le toit.
id.	id.	grange et grenier	20 / 200 } 220	grange réparer le toit. grenier tout en ruine, le mur en bas, le bois déchiré.
Commune	id.	Eglise	12.000	Refaire la voute 6000, orgue 2000, 7 arcs 400, 8 toises 240, 80 bancs 800, 2 clefs 400 planchers 400, reboucher les crevasses 1760
id	id.	Clocher	2200	Réparer 12 arcs, placer 8 clefs, toit et [illegible] à réparer à refaire 40 toises du mur du cimetière 200.
Villa Gustave	id.	maison	450	Refaire 26 toises et cheminée, réparer le toit

Gnadenkapelle Visperterminen

Detailed listings with damage and cost for repair (Kanton Wallis, 1855)

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Visp 1855 (Mw 6.2): Damage

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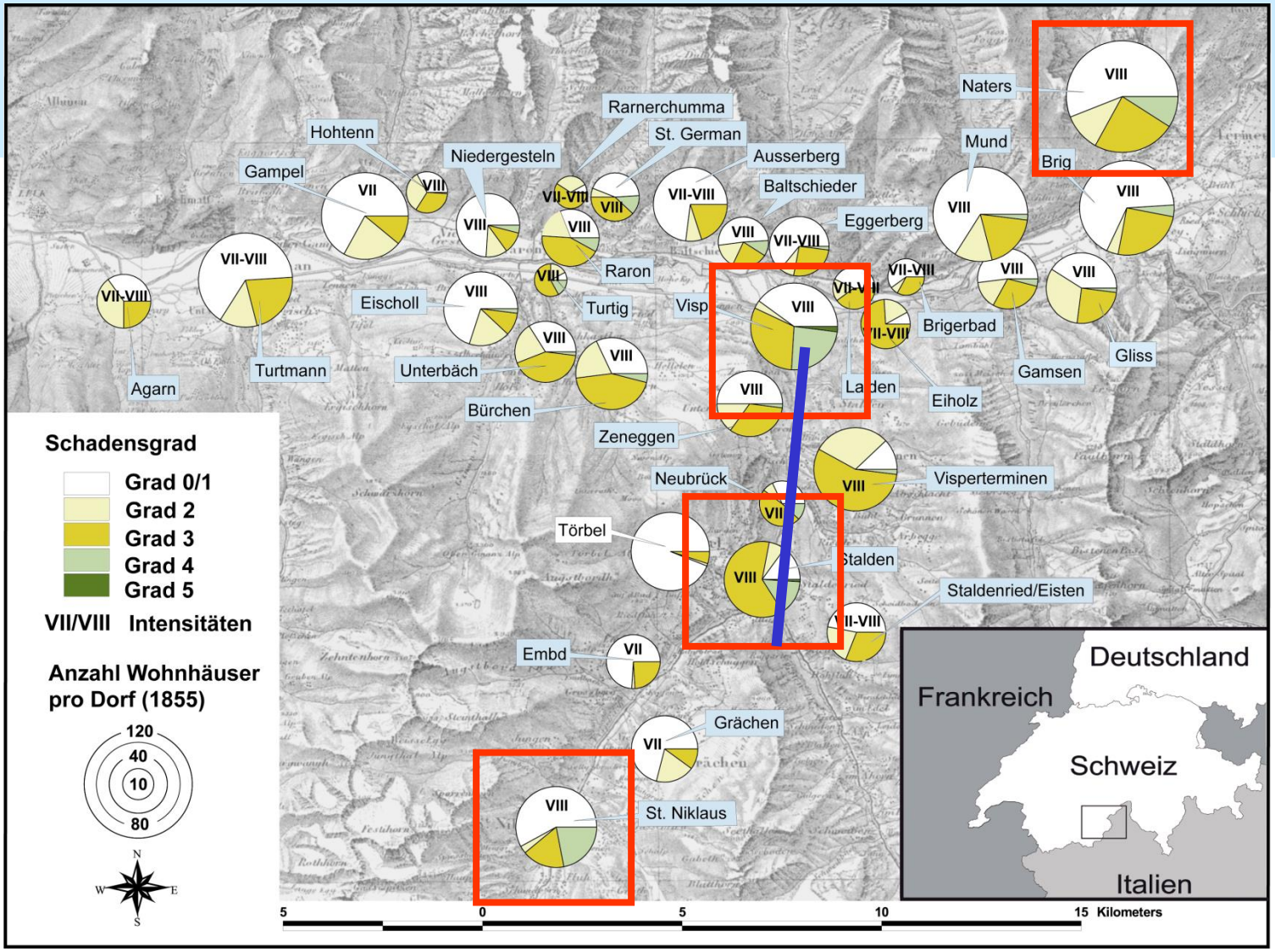

Fritsche et al., 2006

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Visp 1855 (Mw 6.2): Induced effects

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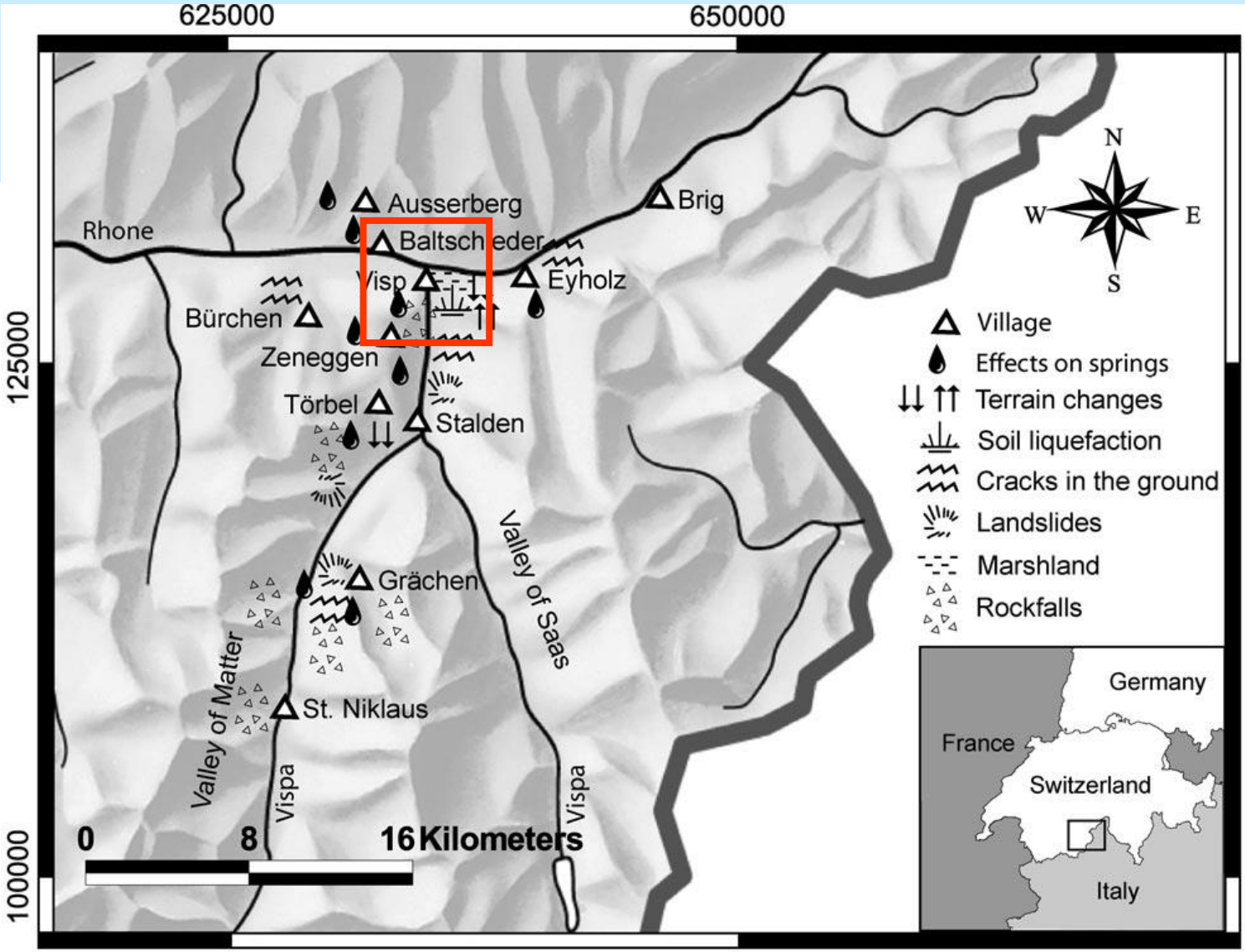

Fritsche et al., 2006

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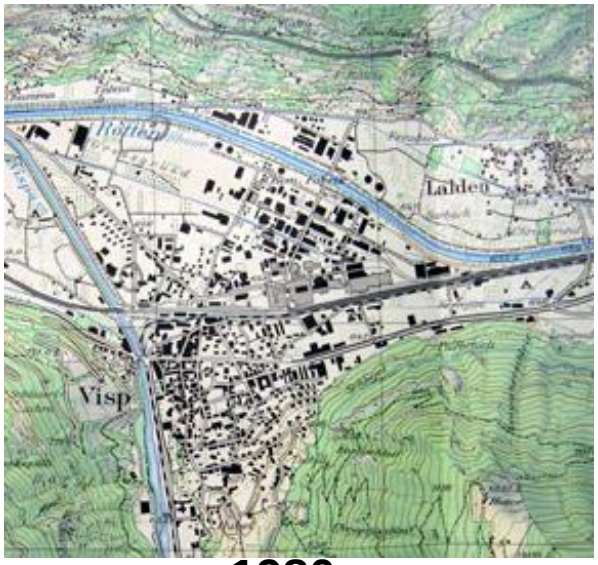
What would happen today?
Increase of risk with time!

Urban development at Visp (Valais)

1850

1940



1980

River Regulation

Today

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Step 1: Development of Models

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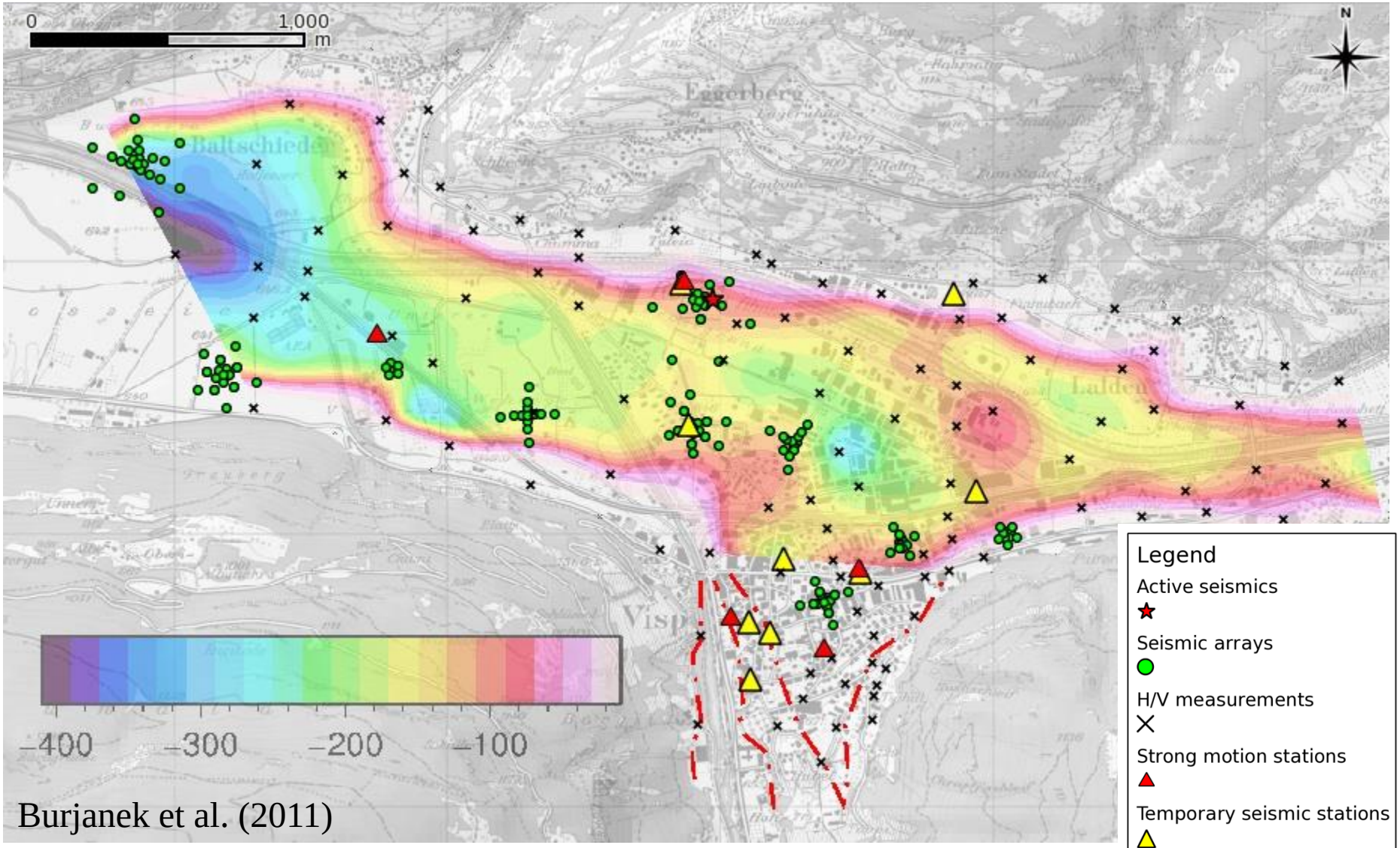
Sedimentary Basin in Visp (Valais)



Burjanek et al. (2011)

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Step 2: Earthquake Monitoring

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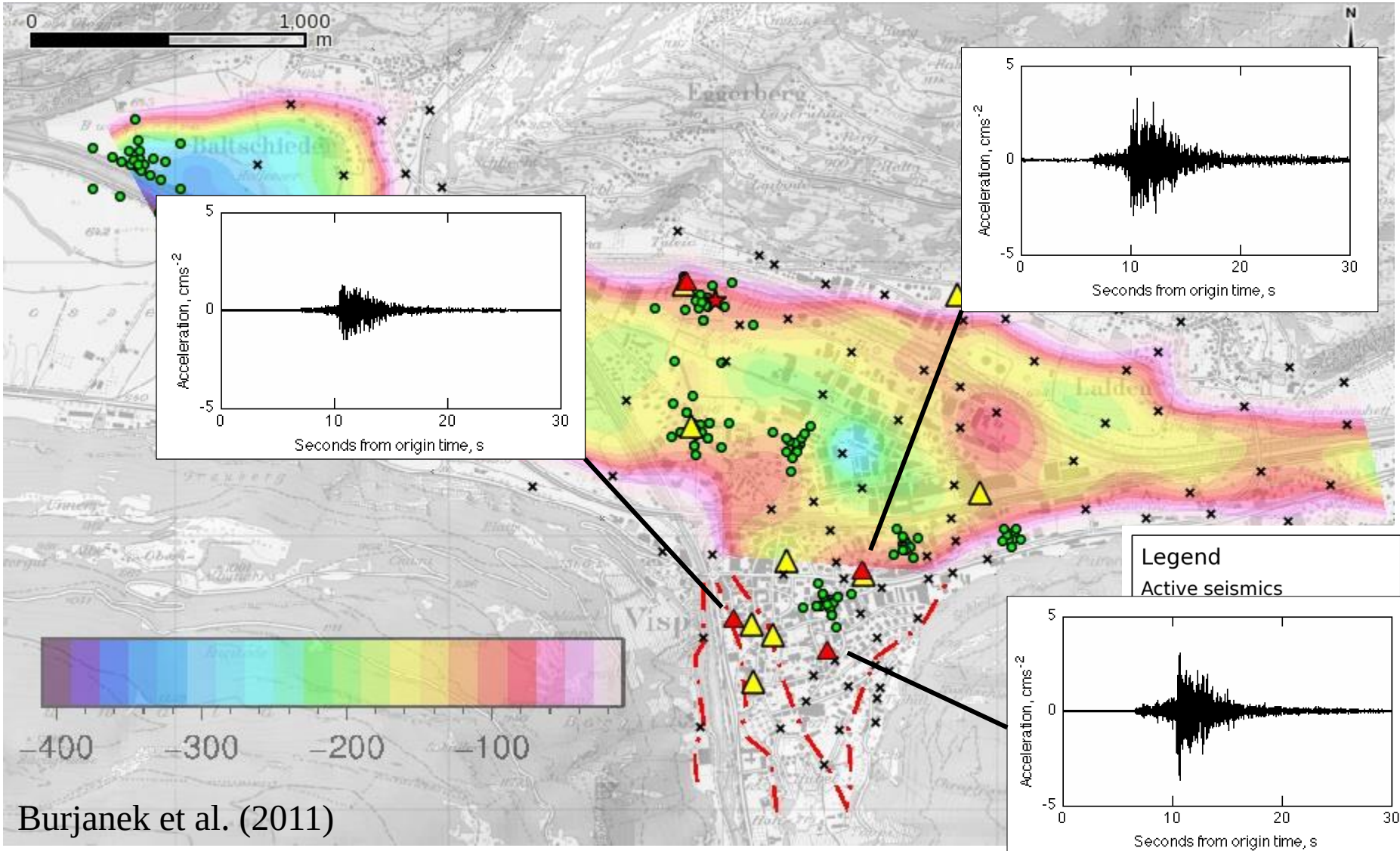
Sedimentary Basin in Visp (Valais)



Burjanek et al. (2011)

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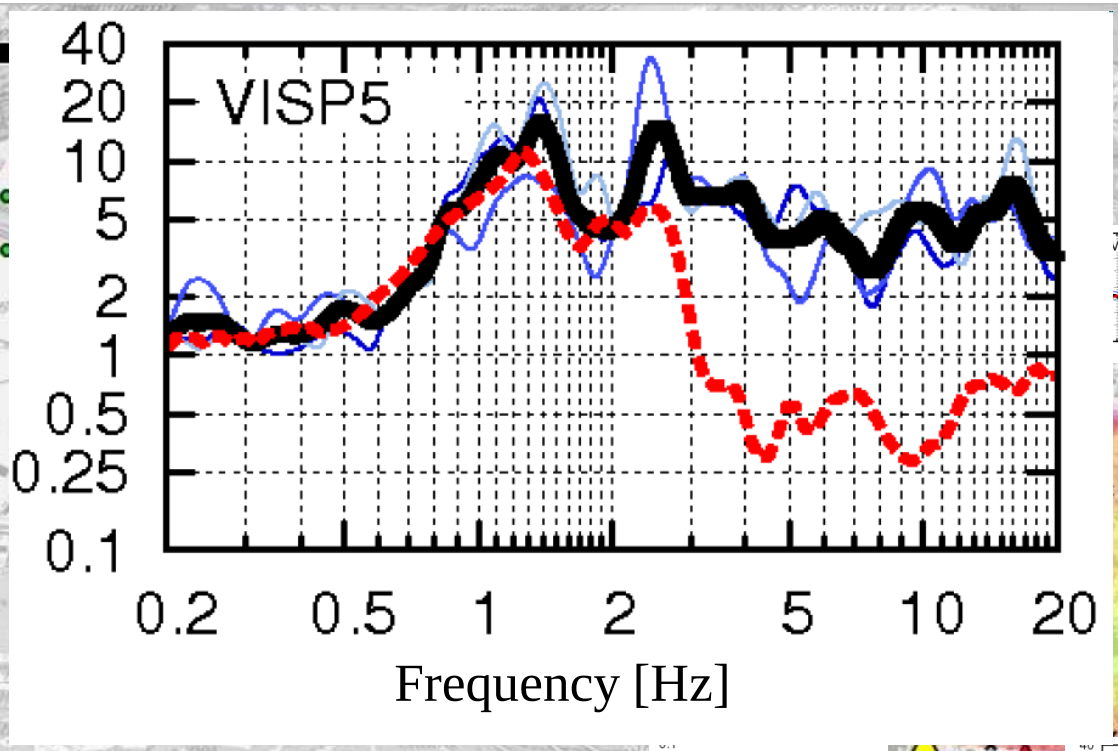
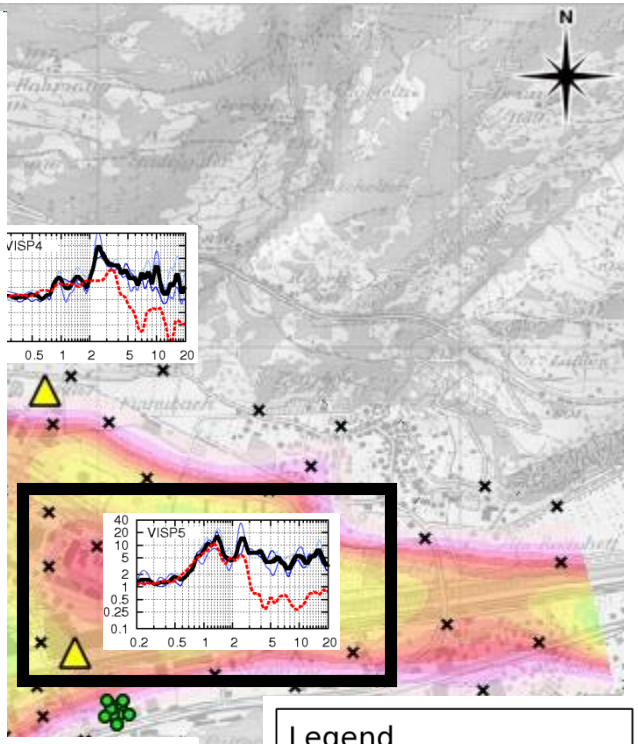
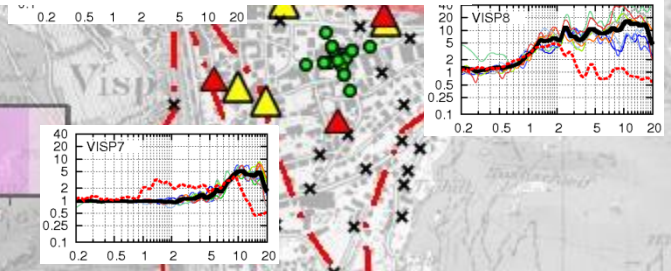
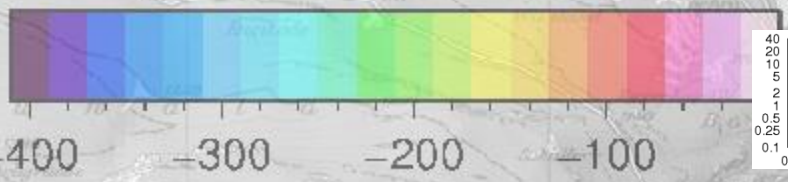
Measured amplifications in Visp









Burjanek et al. (2011)

Legend
- Active seismics
- Seismic arrays
- H/V measurements
- Strong motion stations
- Temporary seismic stations

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Step 3: Numerical Modeling

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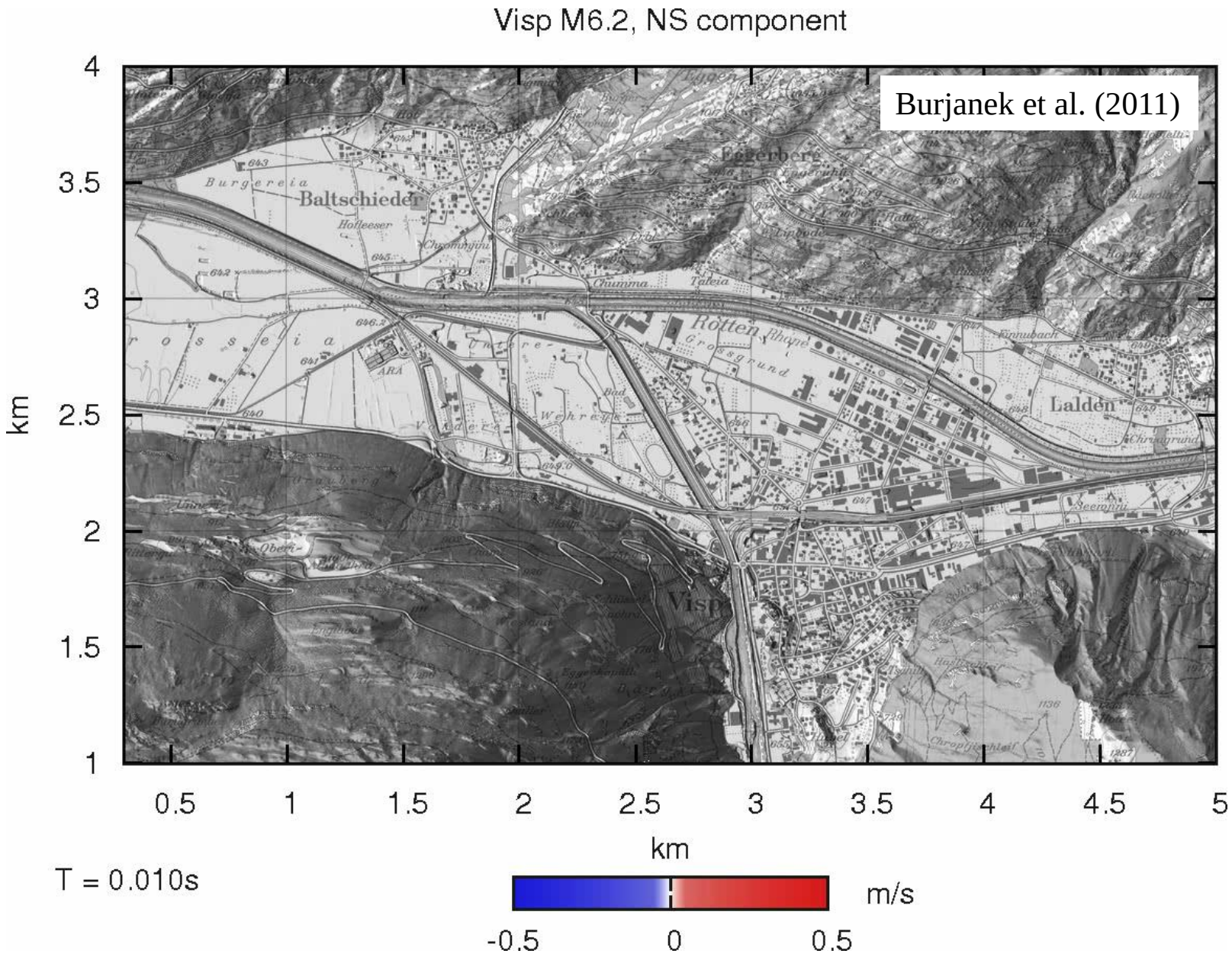
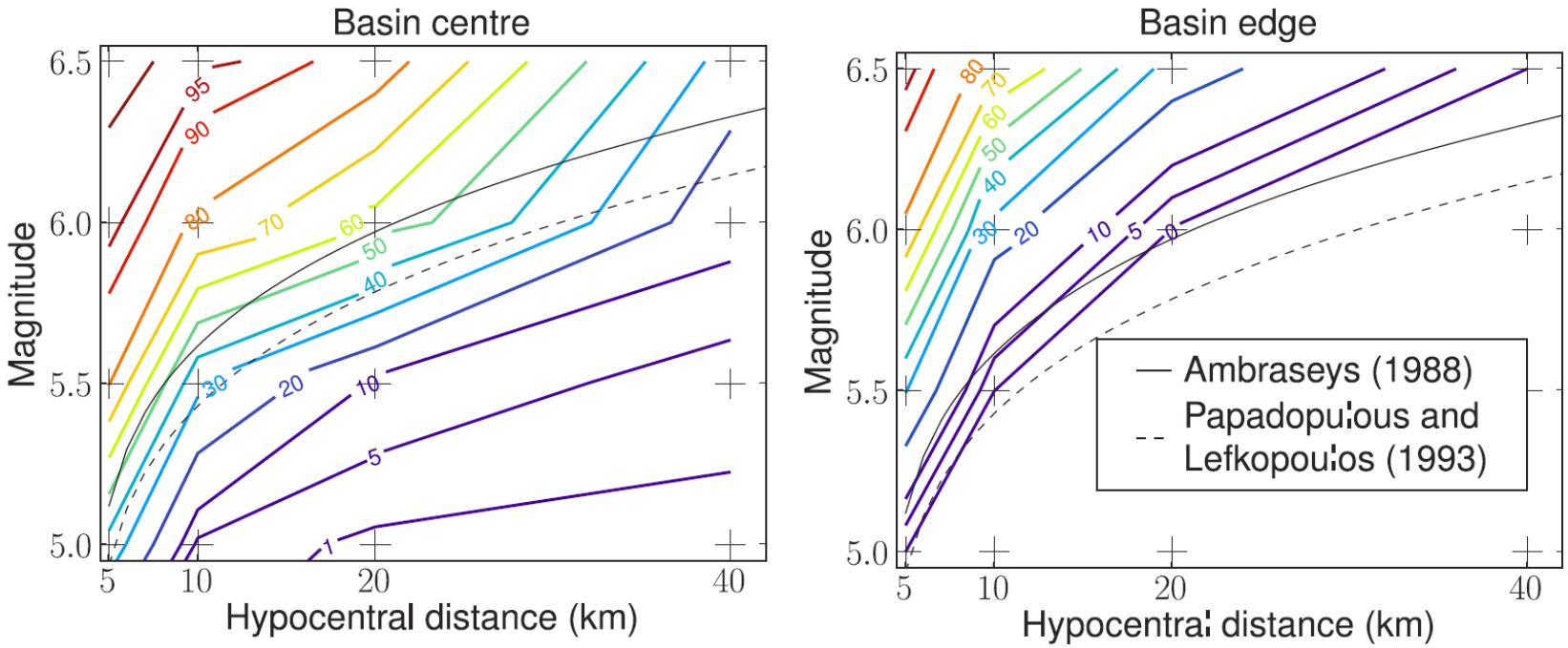


Step 4: Liquefaction of Soils

Investigations for the uppermost layer
taking into account the deep basin at Visp



Roten et al. (2009)

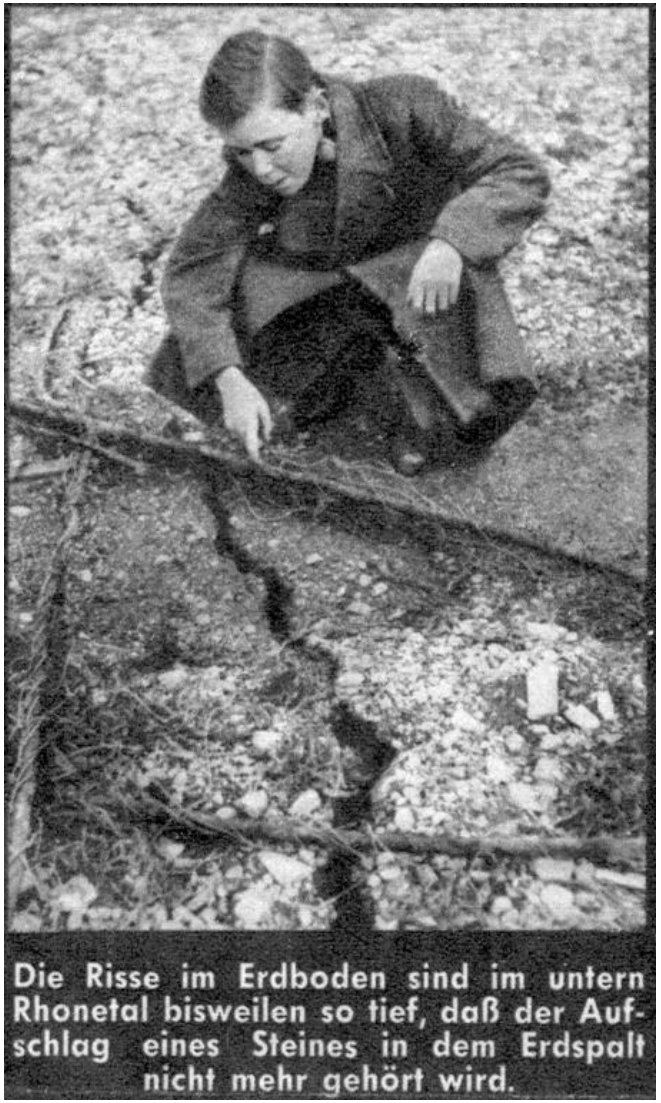
Critical soil characteristics:

fine grained sediments (sand, silt)

shallow ground-water table

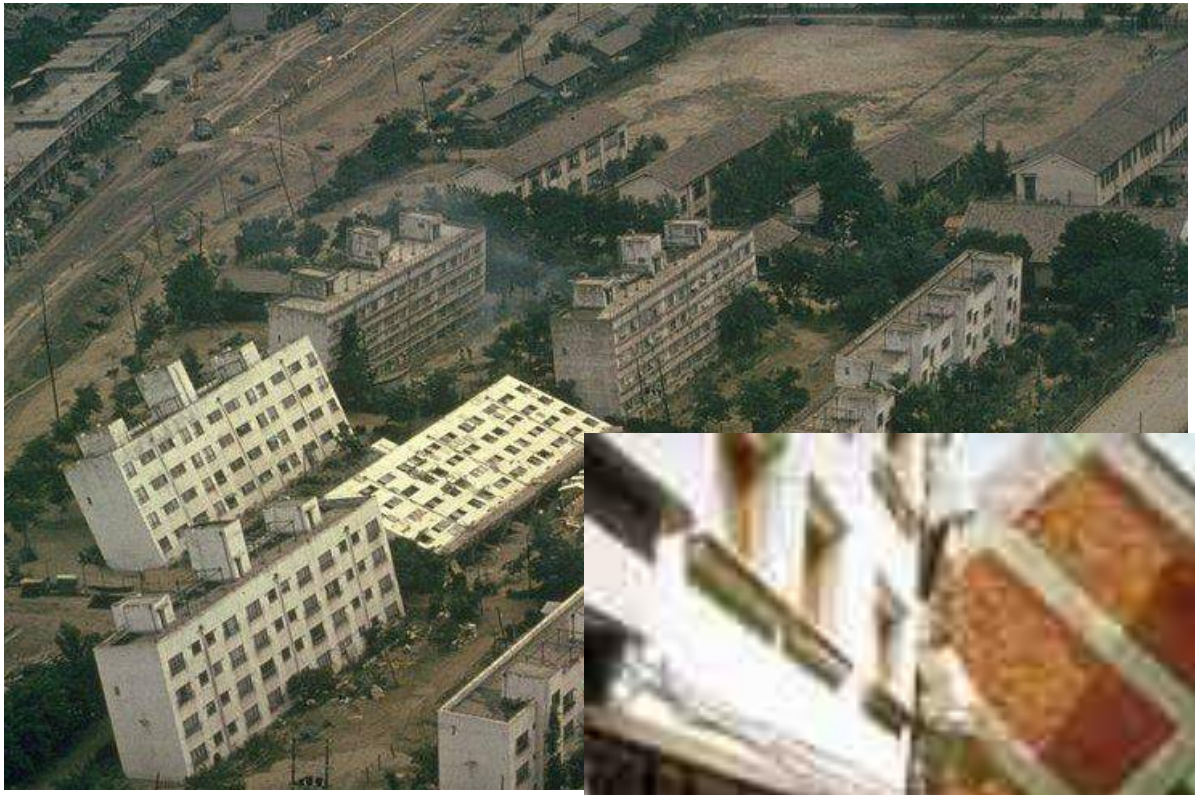
Nonlinear behaviour / soil liquefaction

Kobe 1995



Sion/Sierre 1946

Nonlinear behaviour / soil liquefaction



Niigata
1964

Izmit
1999

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Problems with faults: Impacts on lifelines

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Landers 1992

ChiChi 1999

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Slope instabilites and rock fall

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Izmit 1999

Chi-Chi Taiwan 1999

Wang Renkun

Wenchuan 2008

How can we identify instable slopes?

- If the slope is moving:

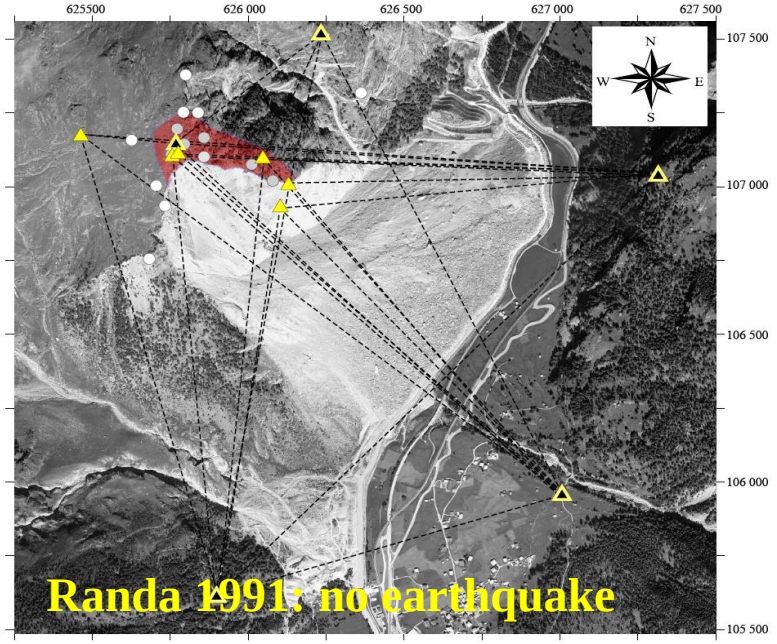
  INSAR, deformation devices, radar, ….

- If the slope is not moving, but instable (e.g. Gotthard 2012):

  Geological inspection (not always reliable)

  Using ambient vibration

Grächen 1755: earthquake



Randa 1991: no earthquake

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Directional Polarisation

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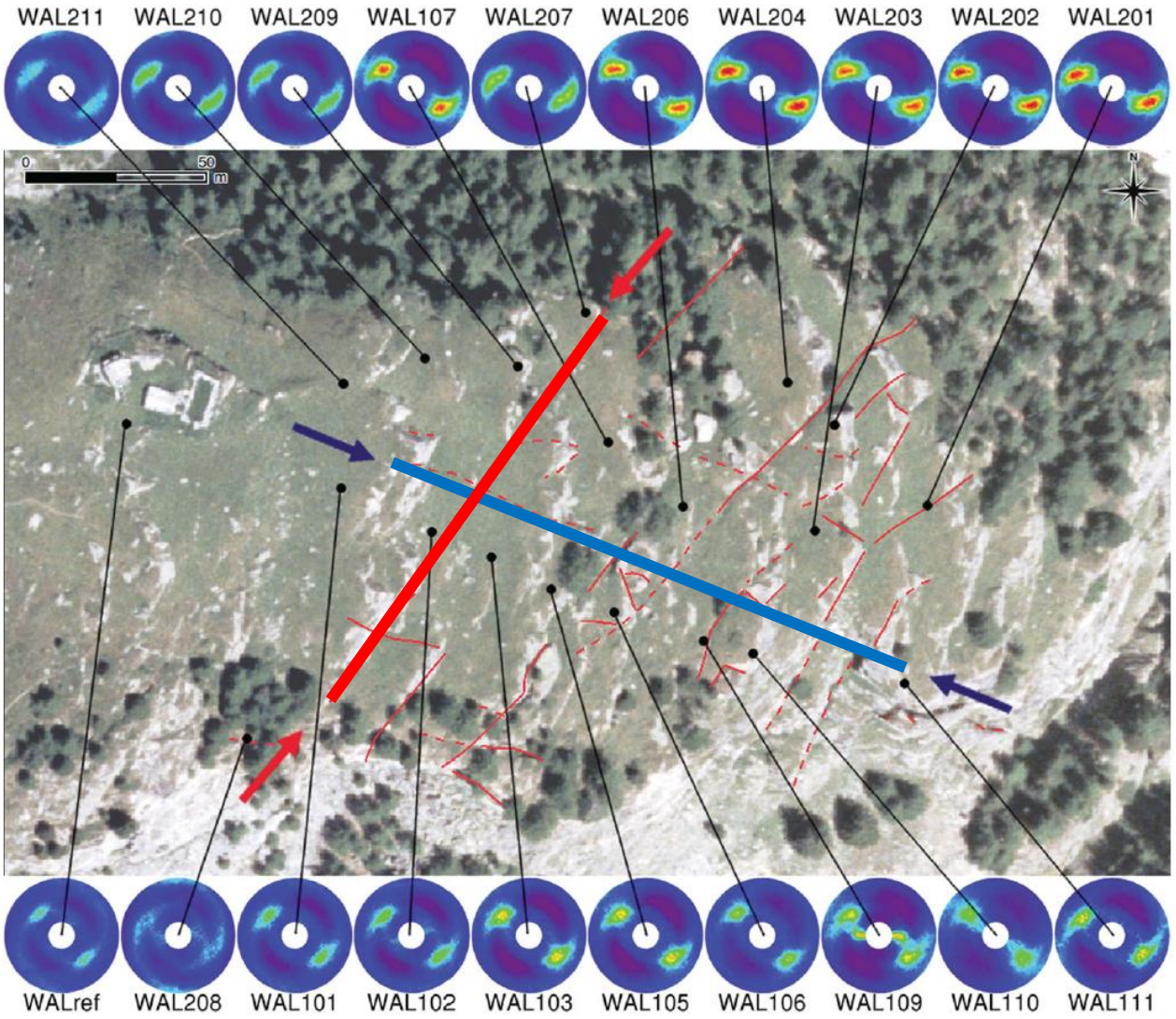
Identification of instable rock-slopes



Site:
Walkerschmatt

Burjanek et al. (2012)

Thank you